# *Implications of threshold relationships for projecting fire-regime responses to climate change*

**Adam M. Young[1], Philip E. Higuera[2], John Abatzoglou[1], Paul Duffy[3], and Feng Sheng Hu[4]**

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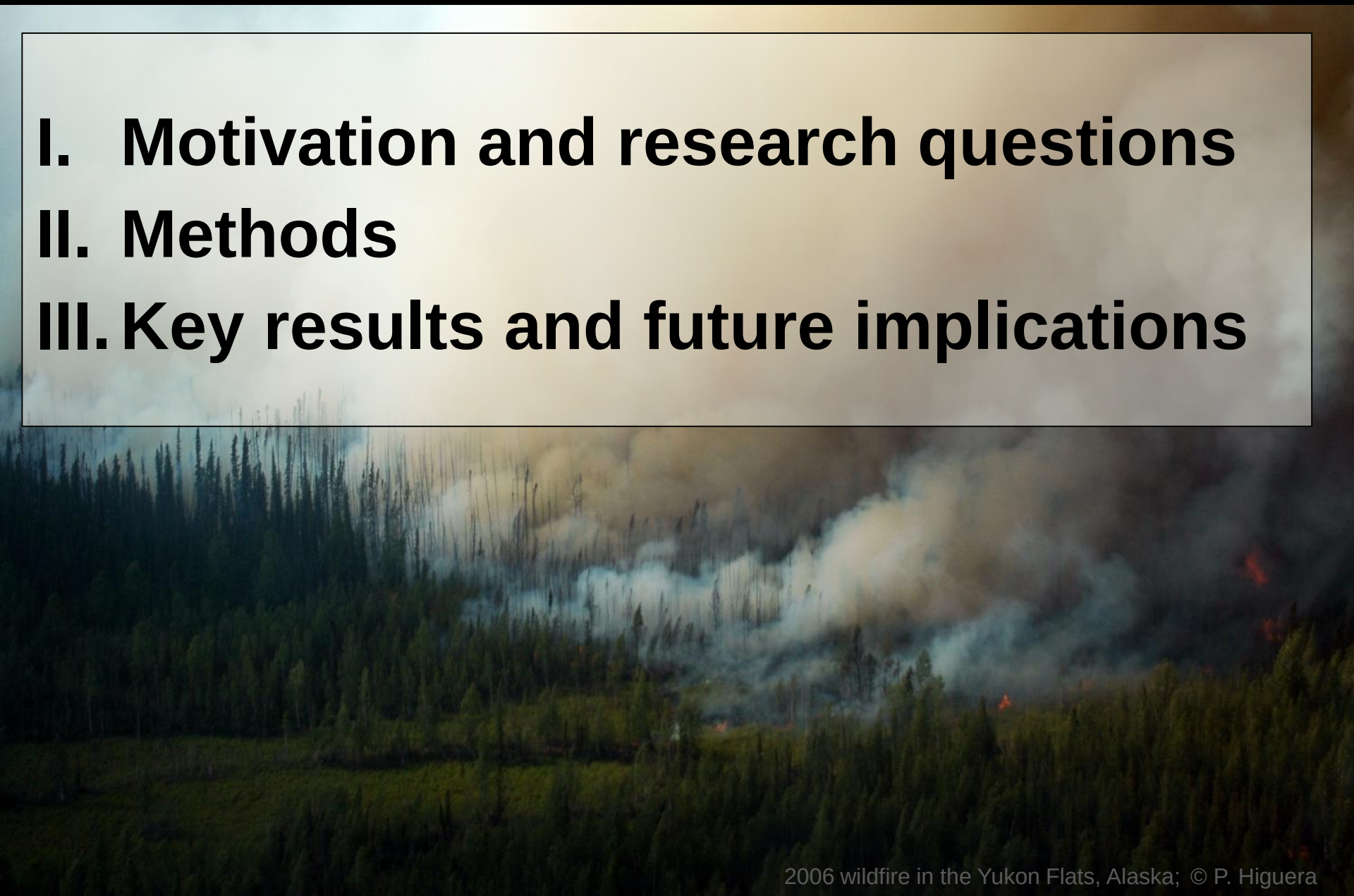
*Alaska Fire Science Consortium*
*April 25, 2017*

2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

# Outline

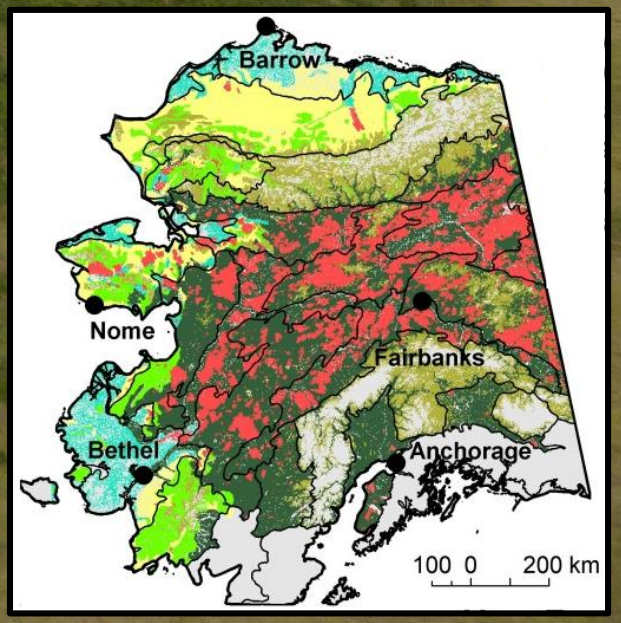
I. Motivation and research questions
II. Methods
III. Key results and future implications



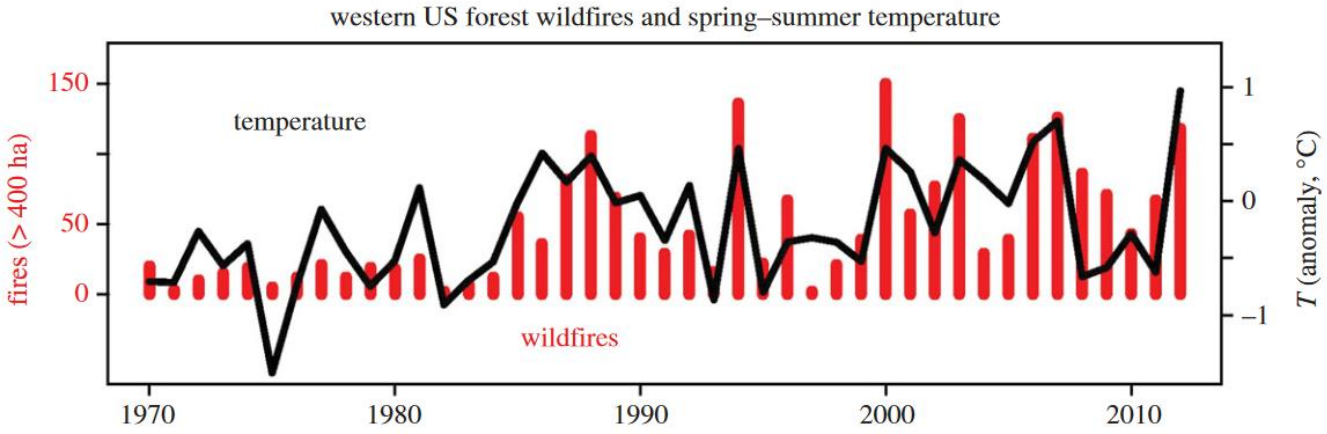
2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

# Fire and climate

- What controlled past variability in fire activity?
- What do these controls imply about responses to future climate change?

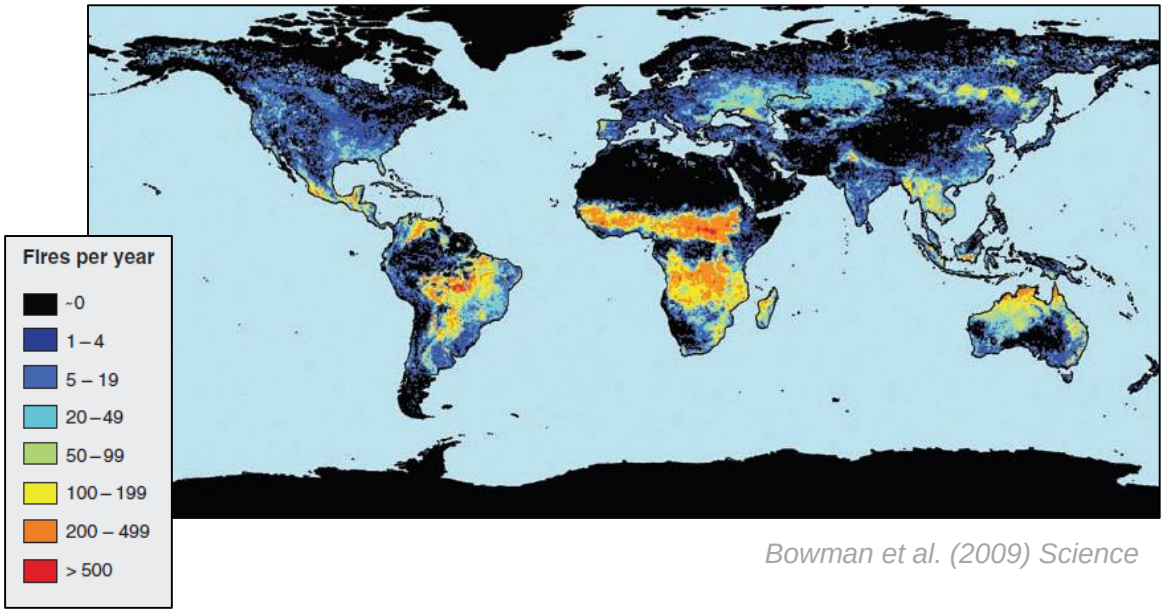


# Fire and climate




*Westerling (2016) Phil Trans B*

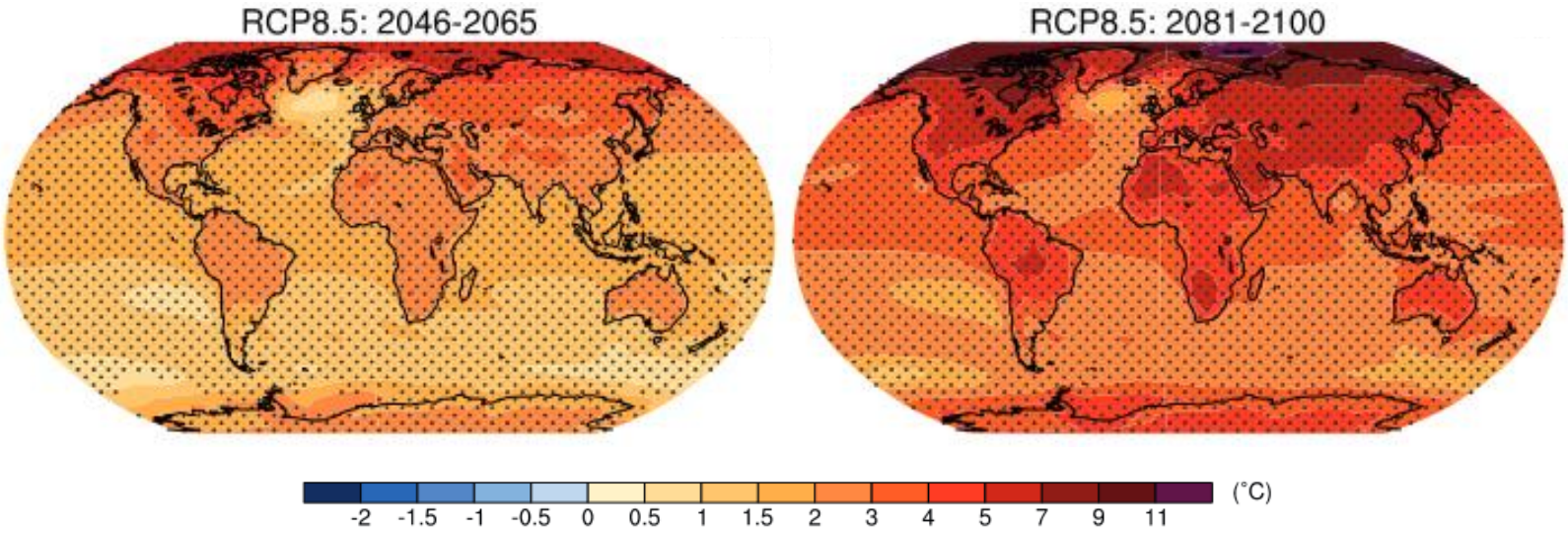
***Climate is a major driver of fire activity**



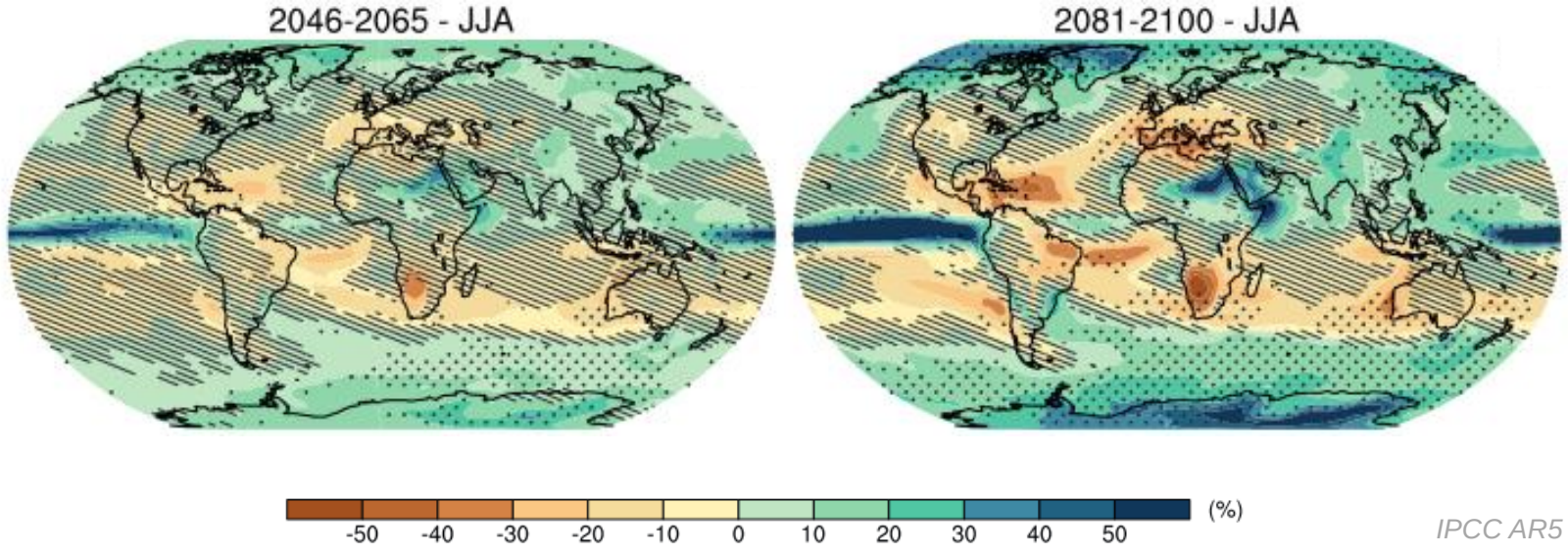

*Bowman et al. (2009) Science*

# Fire and climate

Temperature




Precipitation



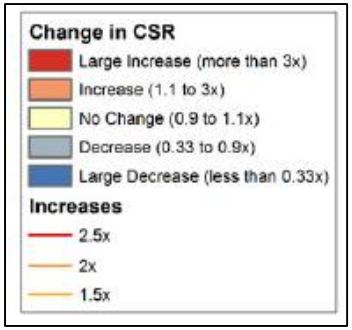

*IPCC AR5 (2013)*

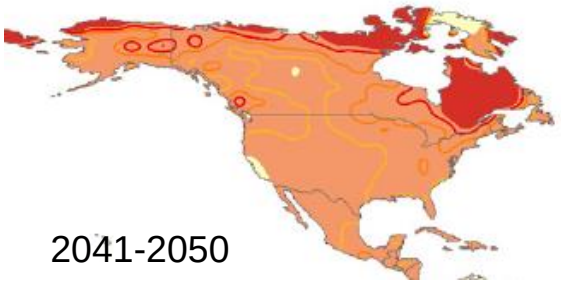
# How can we anticipate future fire activity?

## Three general approaches

*Krawchuk and Moritz (2014) Environmetrics*

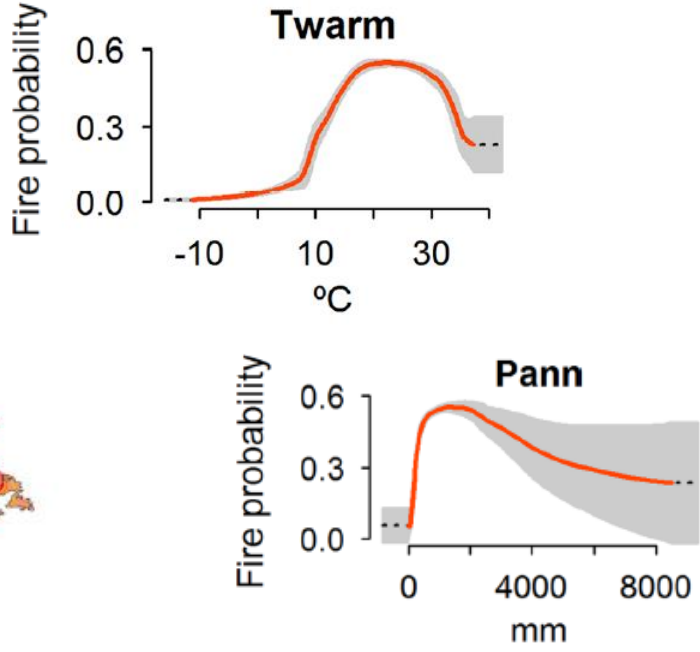
### 1. Fire weather index models



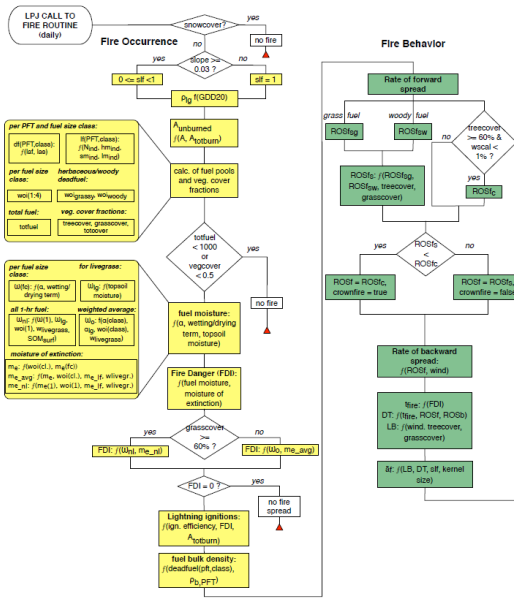

*Flannigan et al. (2013) For Ecol Mgmt*

### 2. Statistical-correlative models




*Moritz et al. (2012) Ecospheres*

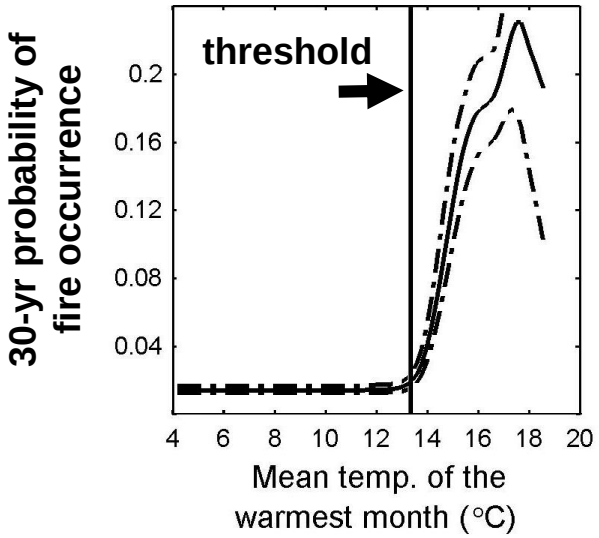
### 3. Fire-process models




*Pfeiffer et al. (2013) Geosci Model Dev*

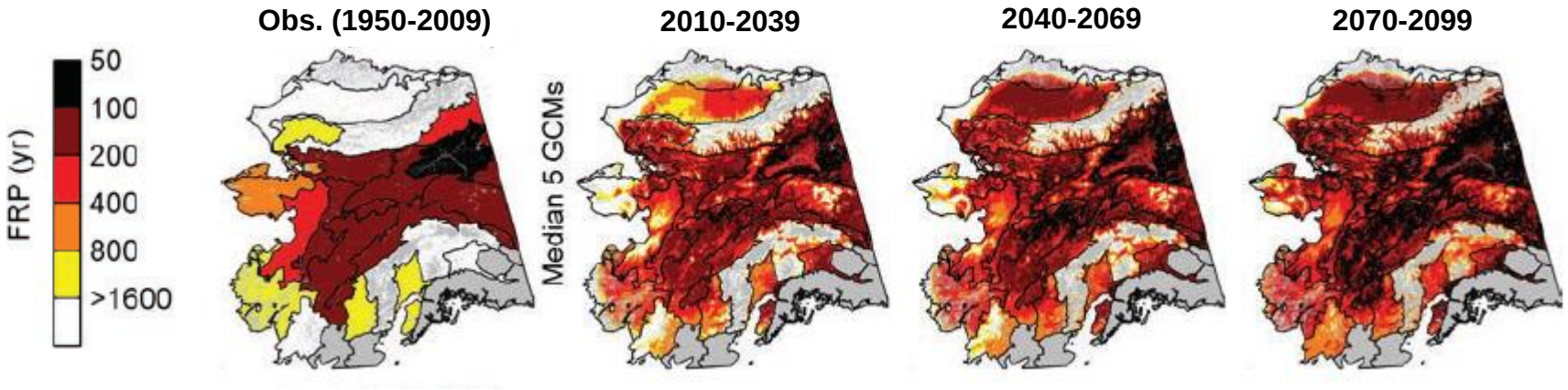
# How can we anticipate future fire activity?

## Fire-climate linkages




***Future climate will differ compared to the observational record.***

## Projected changes in fire activity

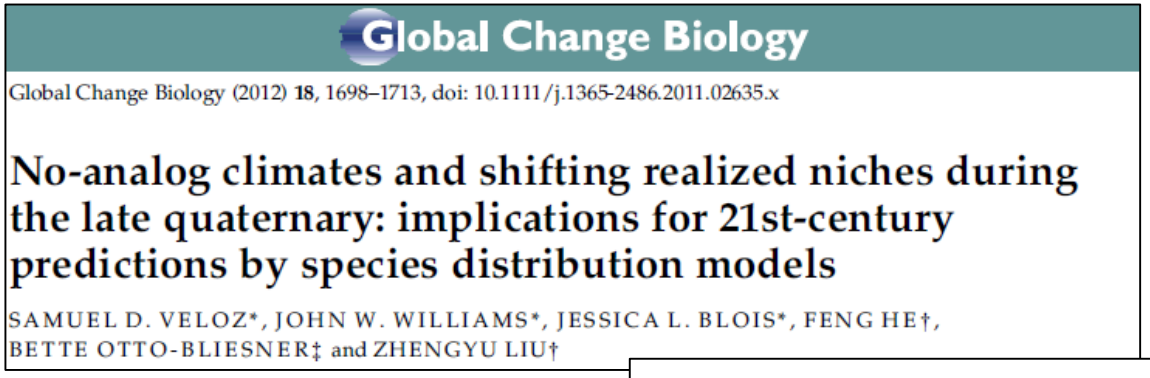



*Young et al. (2017) Ecography*

# Testing model transferability

***Validate models with independent data source outside the observational record***

- **Paleoecological reconstructions**
  - **Offer independent records of ecological dynamics over past millennia**



Global Change Biology

Global Change Biology (2012) **18**, 1698–1713, doi: 10.1111/j.1365-2486.2011.02635.x

No-analog climates and shifting realized niches during the late quaternary: implications for 21st-century predictions by species distribution models

SAMUEL D. VELOZ*, JOHN W. WILLIAMS*, JESSICA L. BLOIS*, FENG HE†, BETTE OTTO-BLIESNER‡ and ZHENGYU LIU†

*Ecology Letters*, (2008) **11**: 357–369 doi: 10.1111/j.1461-0248.2007.01150.x

LETTER

Prediction of plant species distributions across six millennia

*Pearman et al. (2008)*

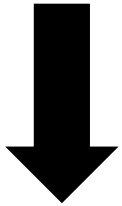
# Limitations to future projections

**Why might projections be wrong?**

**1. Data biases or errors**

- **Used to construct or inform statistical models**
- **e.g., GCM projections**

**2. Changing vegetation and ecosystem dynamics**

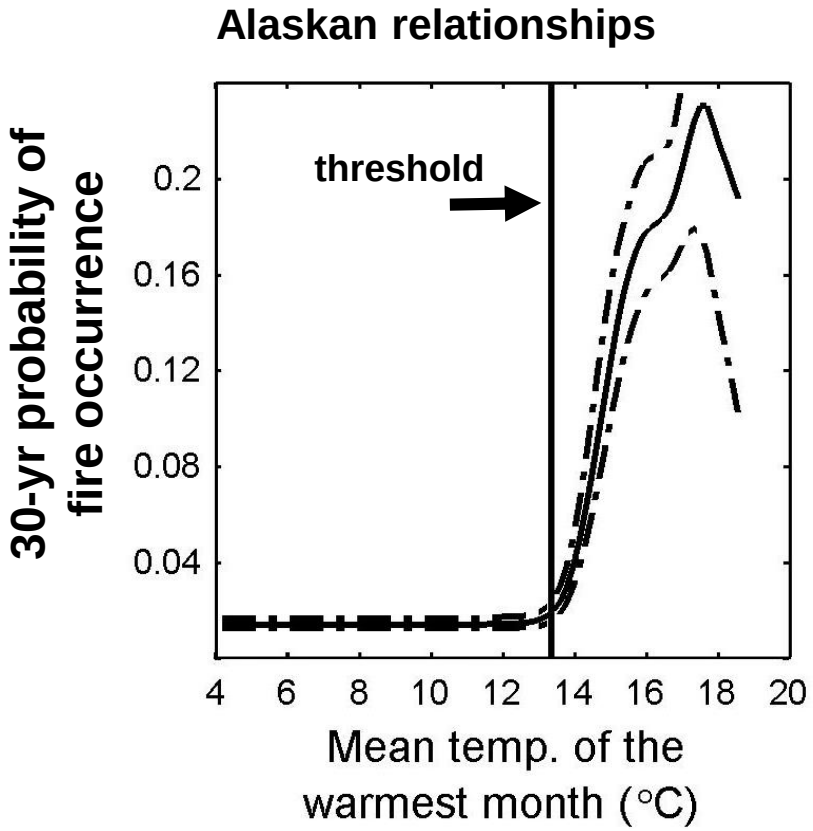


**Changing fire-climate relationships**

# Nature of fire-climate relationships

***Fire-climate relationships are nonlinear and contain thresholds**

***Small errors or changes may significantly change predictions**




*Young et al. (2017) Ecography*

# Key research questions

(1) How do threshold relationships impact statistical predictions outside the observational range?

(2) How sensitive are predictions to modified fire-climate relationships?

(3) What are the implications of using threshold relationships to project 21$^{st}$-century changes?

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   2. Model-paleodata comparisons

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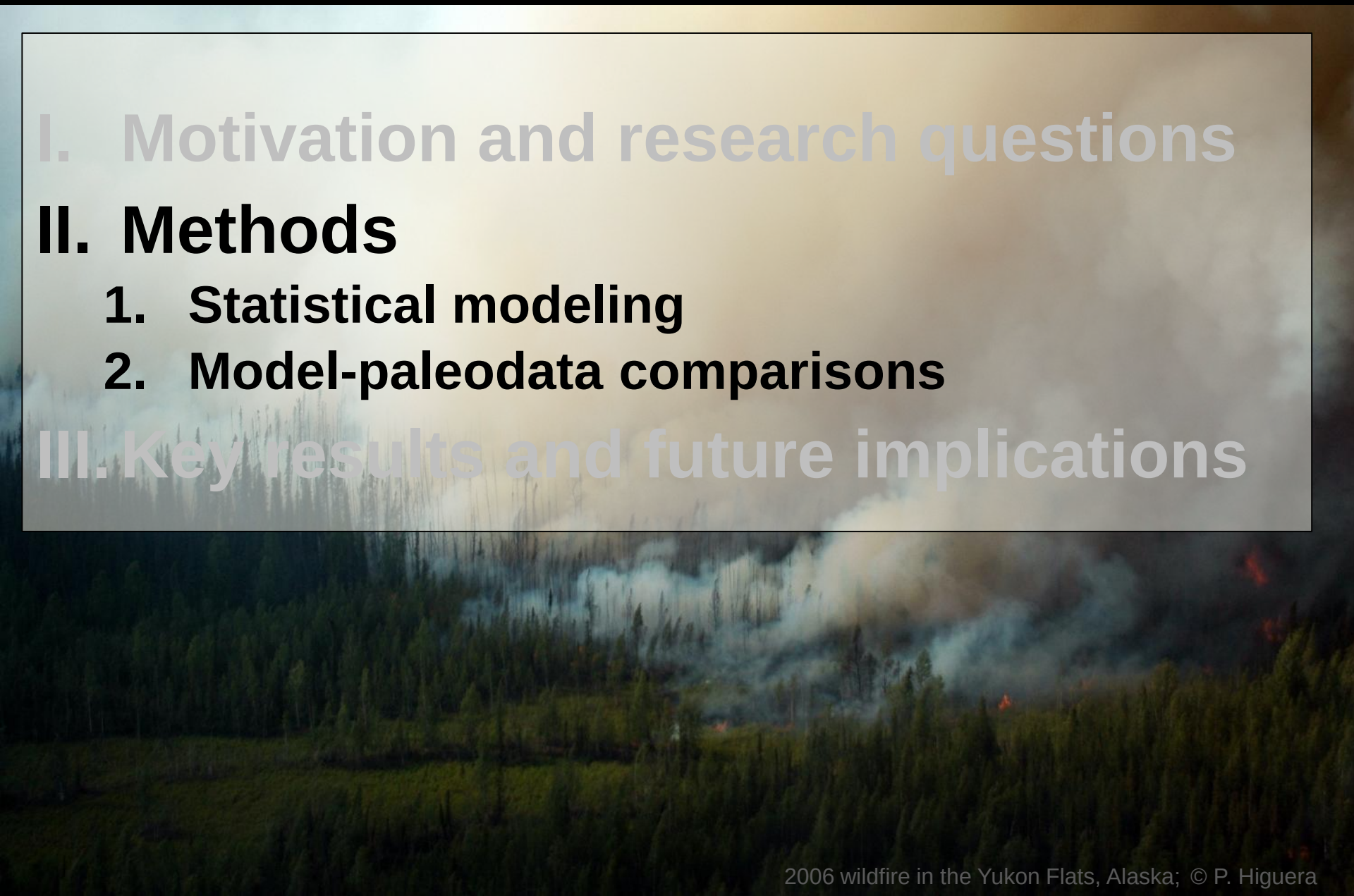


2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

# Statistical modeling in Alaska

Research

Ecography 40: 606–617, 2017
doi: 10.1111/ecog.02205

Subject Editor: Jessica Blois. Editor-in-Chief: Miguel Araújo. Accepted 30 March 2016

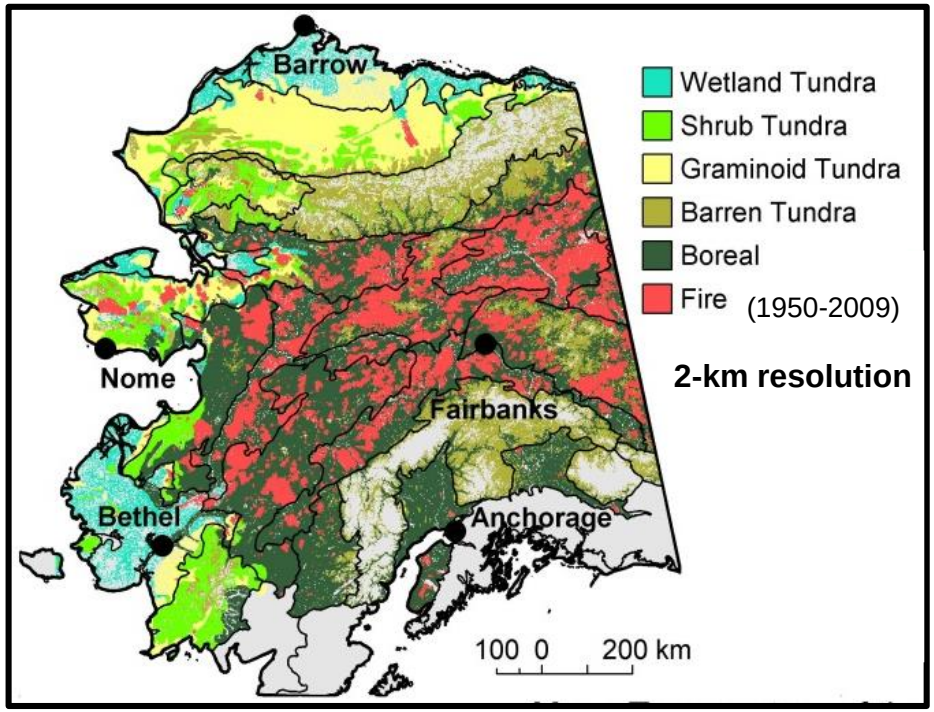
**Climatic thresholds shape northern high-latitude fire regimes and imply vulnerability to future climate change**

Adam M. Young, Philip E. Higuera, Paul A. Duffy and Feng Sheng Hu

**Modeled P(fire) at 30-yr timescales**

**Spatial variation in fire activity**

**Presence/absence approach**



# Statistical models

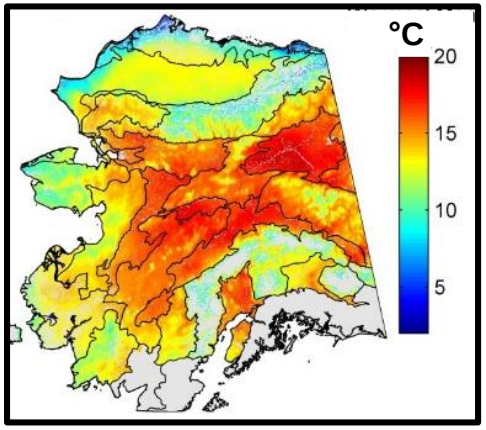
Boosted Regression Trees (BRTs)

**- Machine learning algorithm**

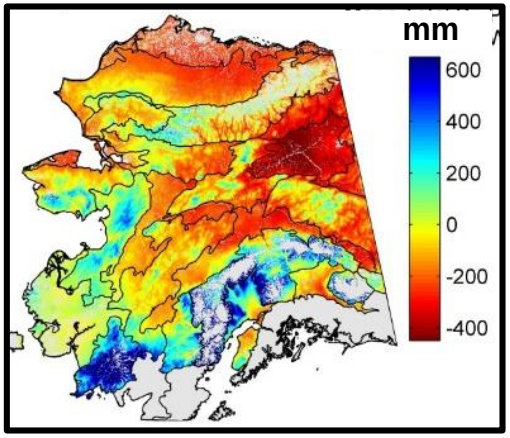
**- Able to fit complex, nonlinear relationships between response and explanatory variables**

## Explanatory Variables (1950-2009)

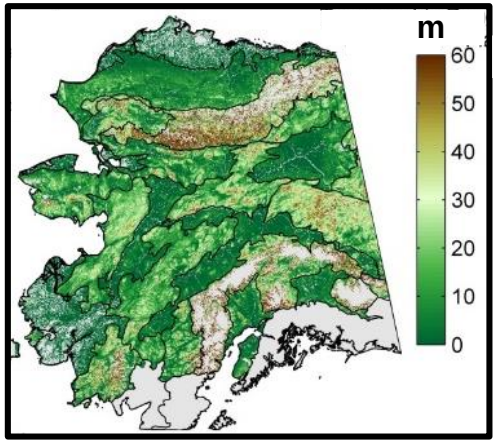
**Temp. Warm. Month**



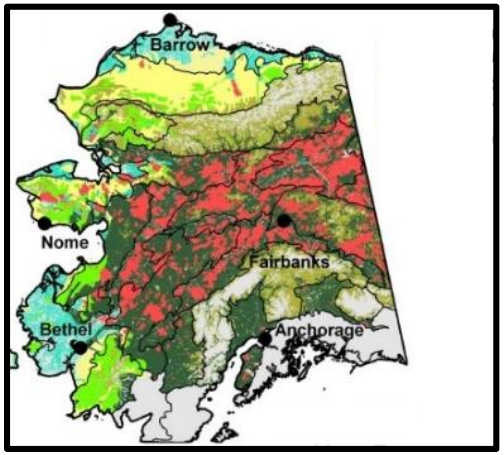

**Ann. Moisture Avail. (P-PET)**




**Topography**




**Veg. Type**

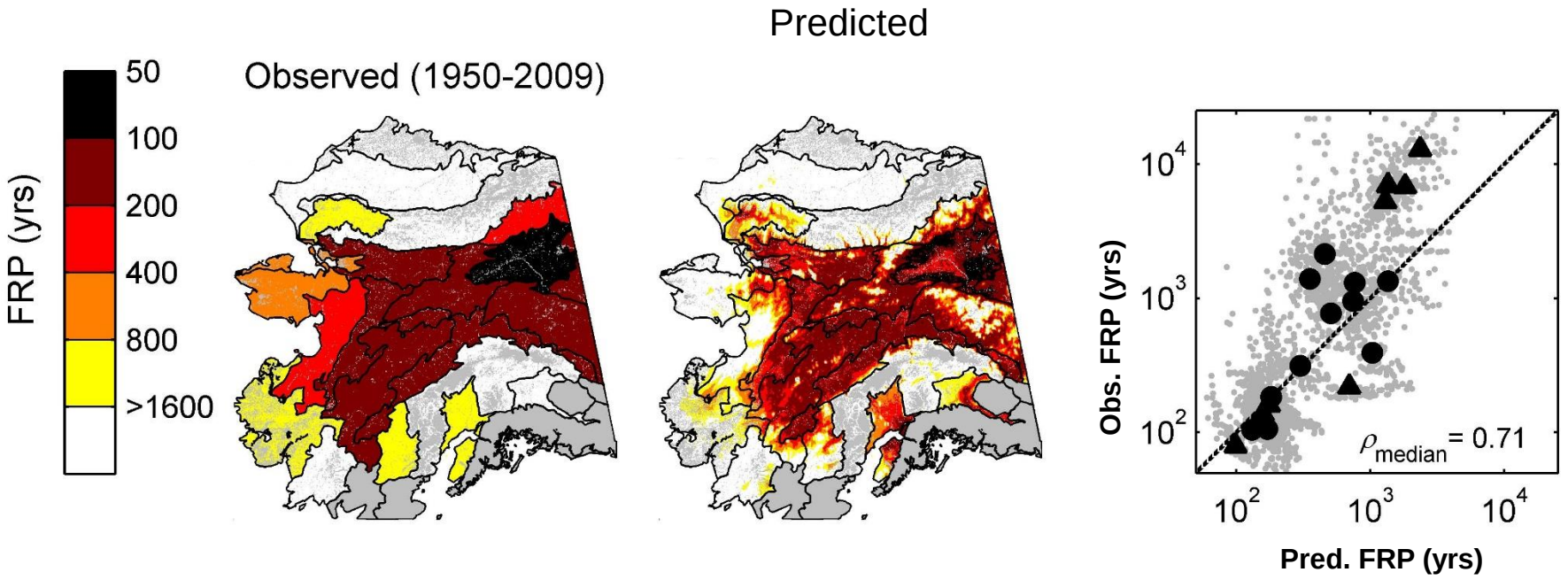



Fire Data: Alaska Large Fire Database (fire.ak.blm.gov)

Veg. Data: Circumpolar Arctic Veg. Map (www.geobotany.uaf.edu/cavm)

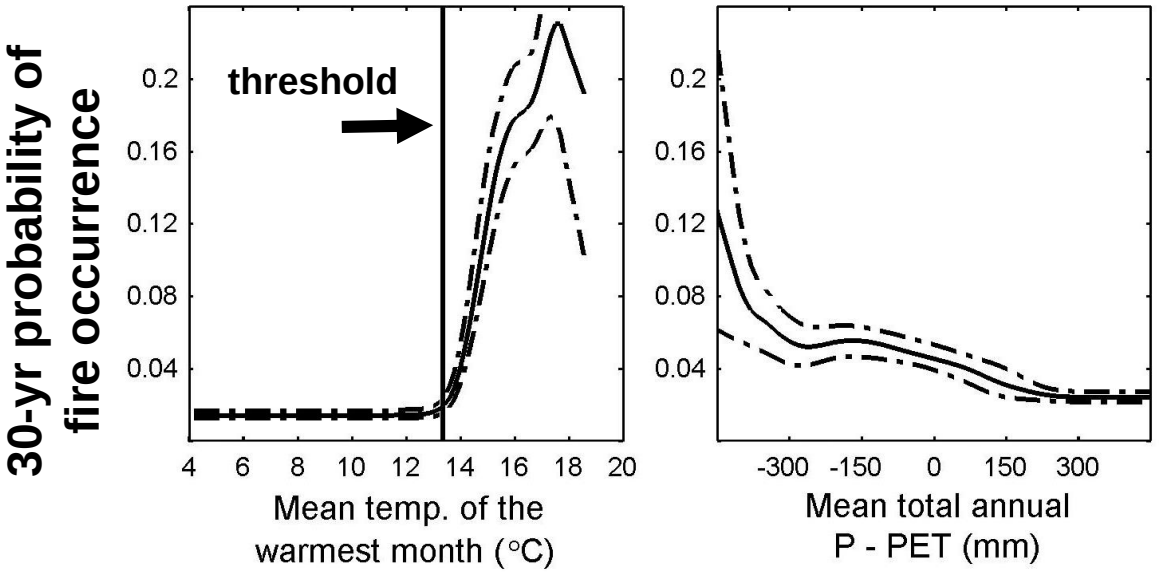
Climate Data: Scenarios Network for Alaska and Arctic Planning (www.snap.uaf.edu)

# Model performance



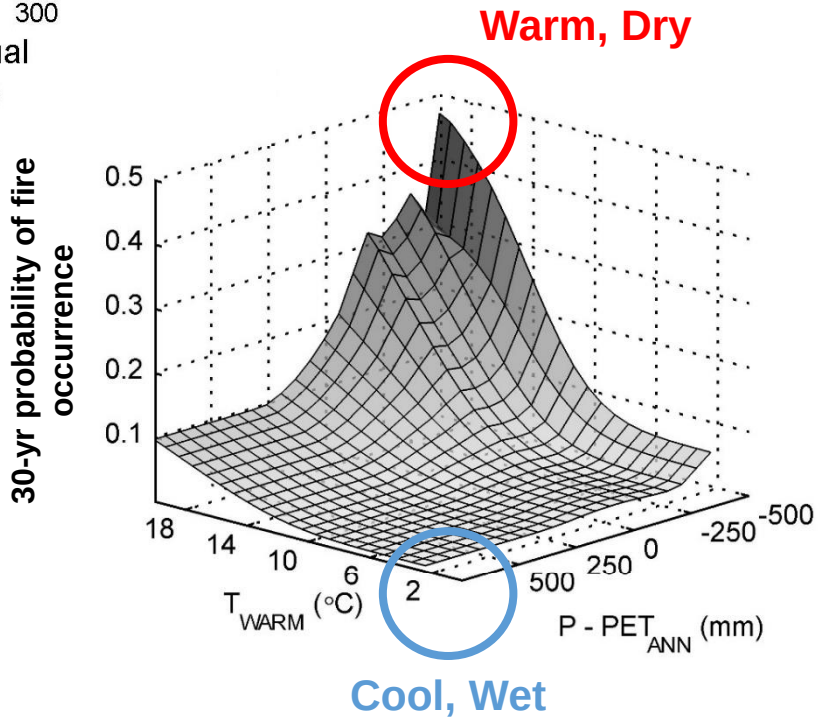

***Statistical models explain spatial variability in fire presence/absence***

# Historical fire-climate relationships




***Non-linear fire-climate relationships reveal thresholds**

***Small climatic changes may result in large fire regime changes**



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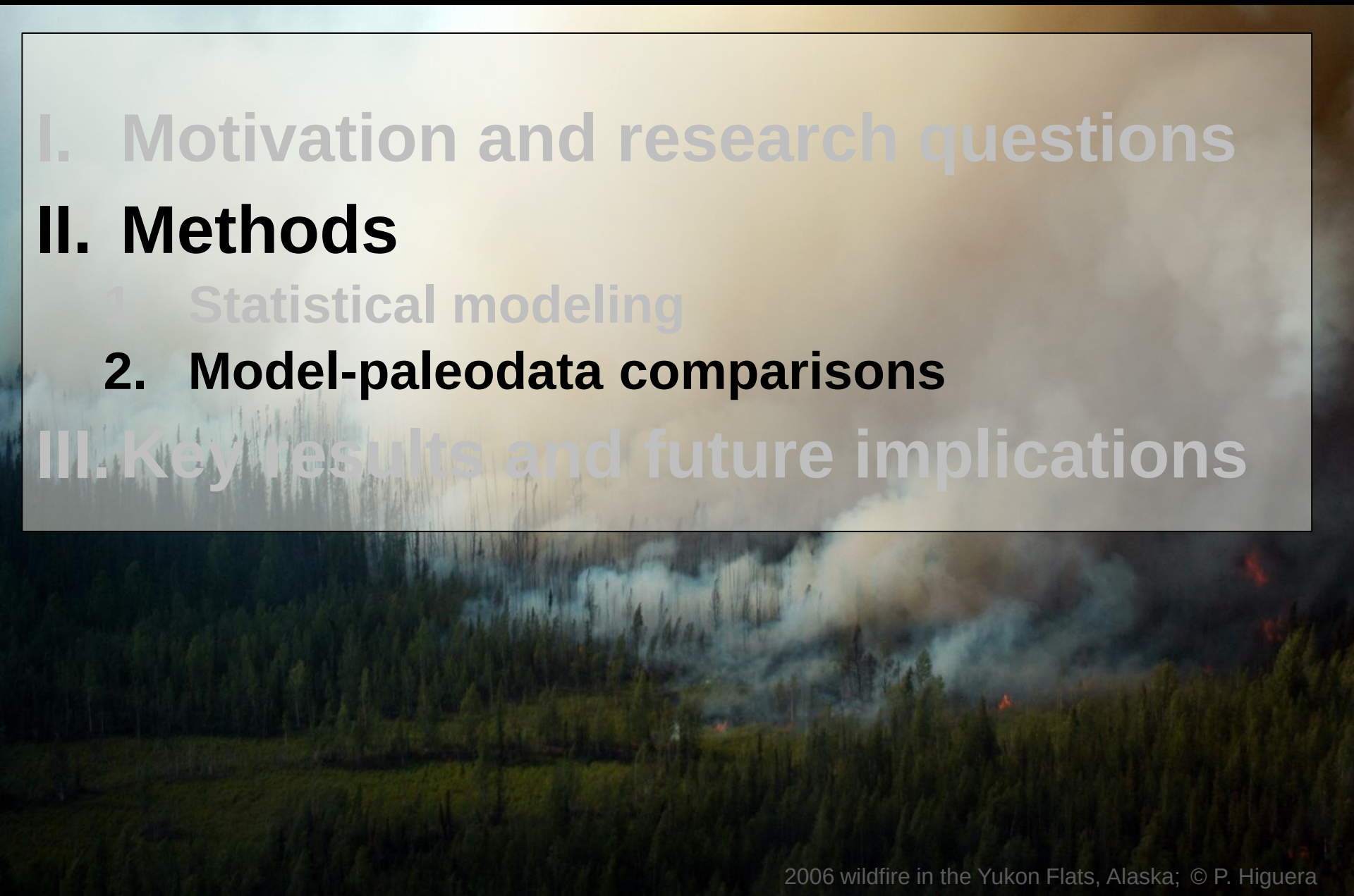


2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

# Predicting fire activity for 850-1850 CE

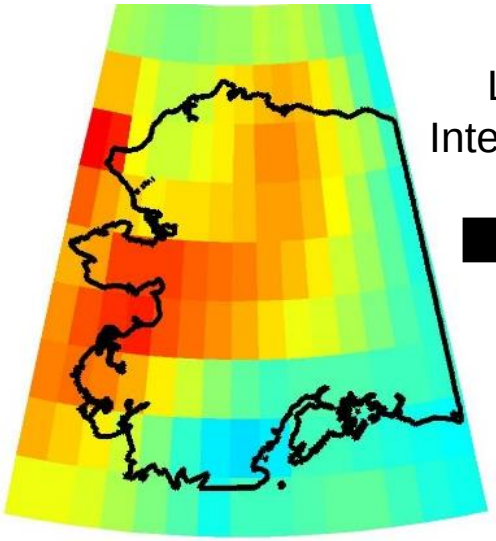
## Use Global Climate Model (GCMs) experiments

### Step 1: Select "best" GCMs

I. GISS-E2-R
II. MPI-ESM-P
III. MRI-CGCM3

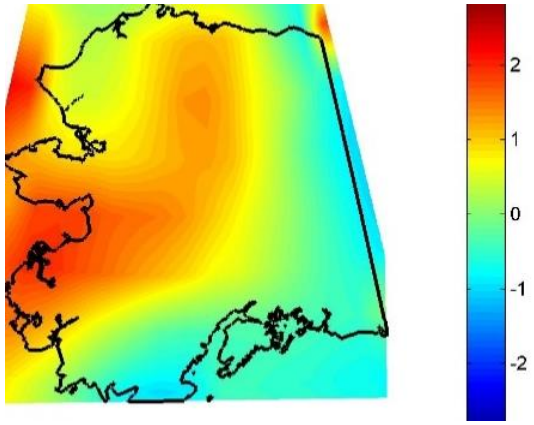
### Step 2: Downscale GCM data for 850-1850 CE

Native GCM Resolution



Linear Interpolation

Desired resolution (2 km)




e.g., 1991 July temp. anomalies (°C)

### Step 3: Create 30-yr climatologies in AK (per pixel)

# Alaskan paleofire records

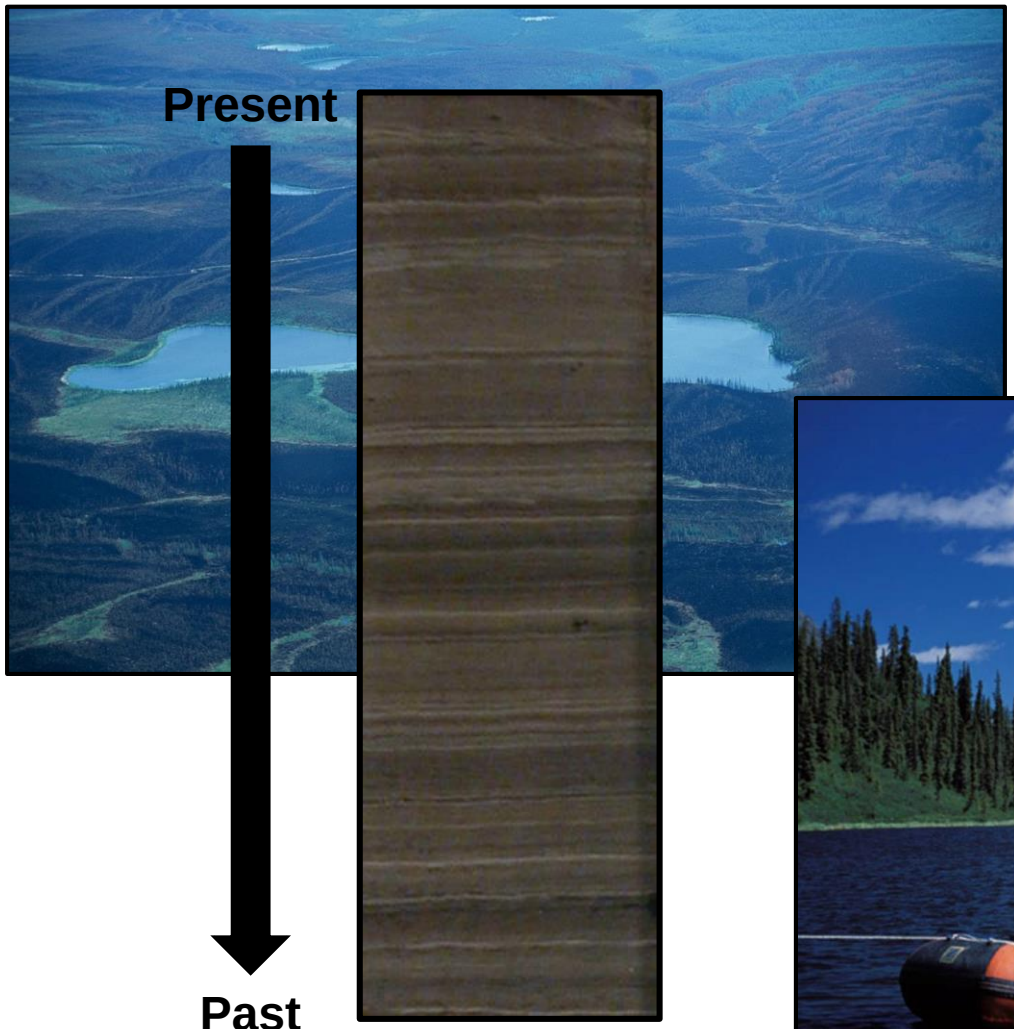
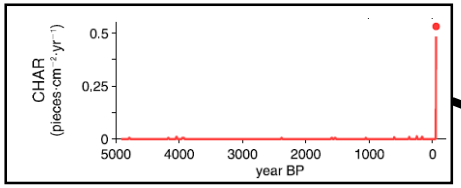
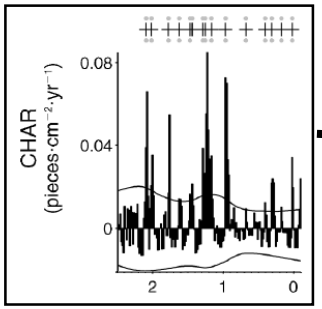
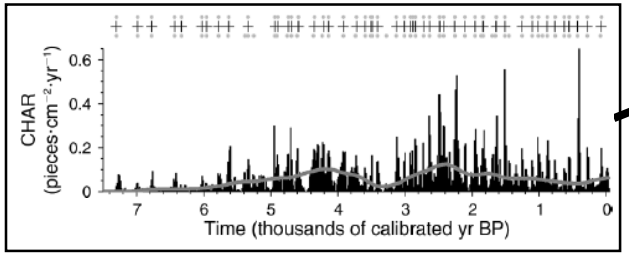


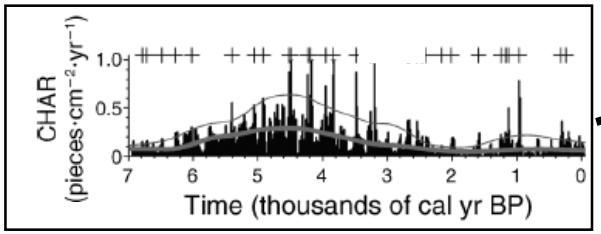

Photo Credits: *P. Higuera (2002)*

# Alaskan paleofire records

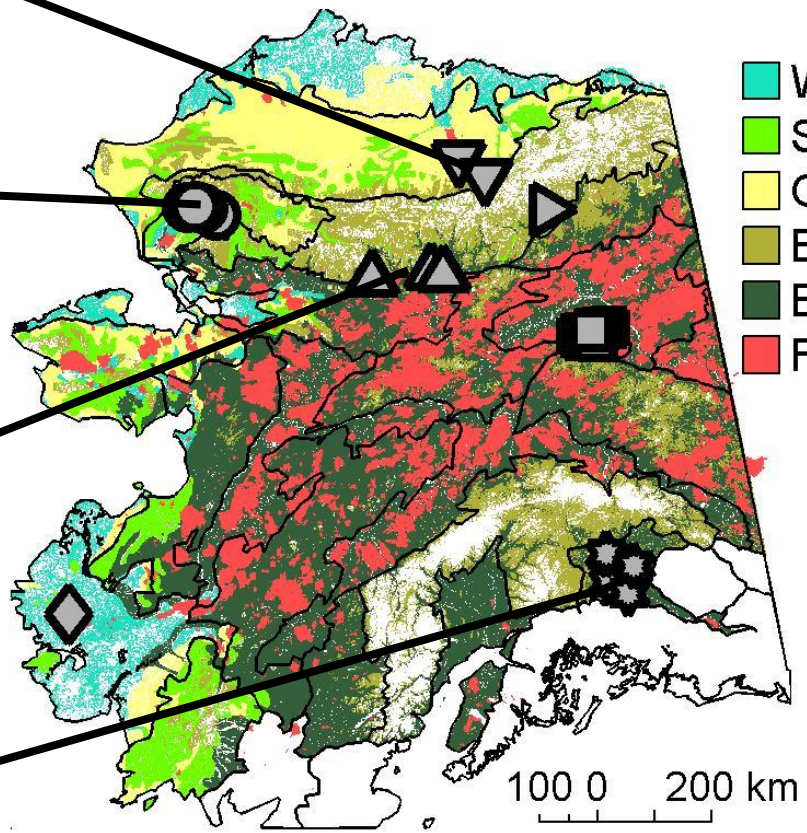


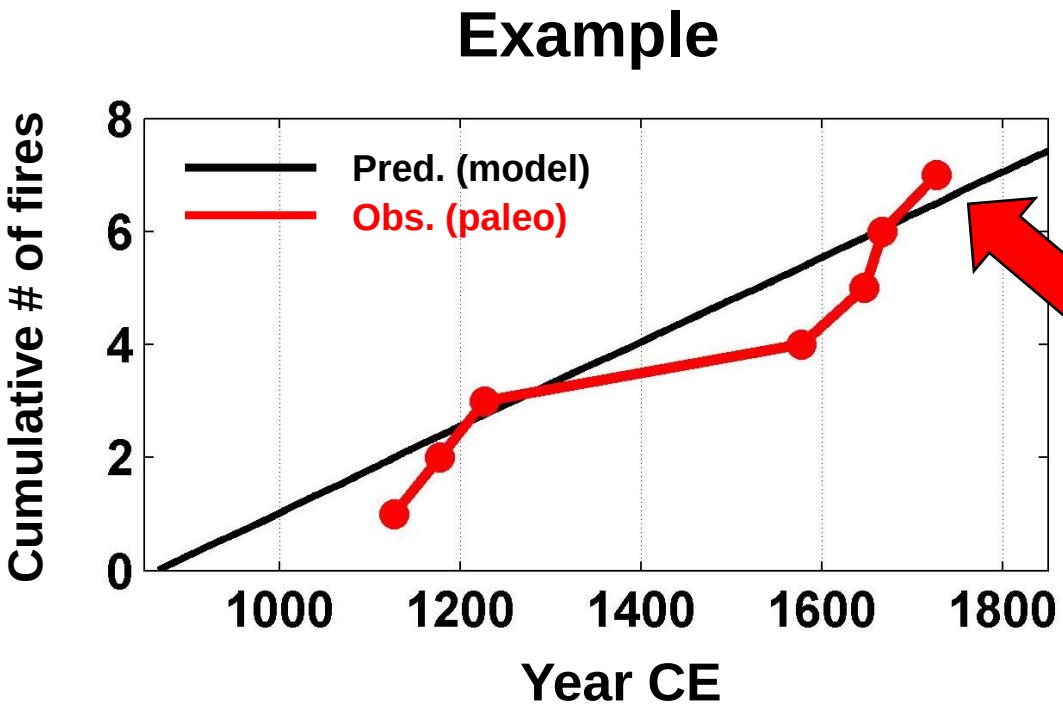

*CHAR = Charcoal Accumulation Rate*




**29 fire-history reconstructions in AK**

*Barrett et al. (2013) Ecology*; *Chipman et al. (2015) Biogeosci*; *Higuera et al. (2009) Eco Mono*; *Higuera et al. (2011) Eco Apps*; *Hu et al. (2010) JGR*; *Kelly et al. (PNAS)*

# Model-paleodata comparisons




***Pred. = 7.21 Fires/1000 yr***

***Obs. = 7 Fires/1000 yr***

- **Evaluating total number of fires for 850-1850 CE**
- **<u>NOT</u> evaluating predictions over time**

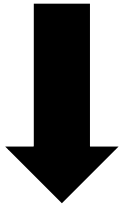
# Limitations to future projections

**Why might projections be wrong?**

**1. Data biases or errors**

- **Used to construct or inform statistical models**
- **e.g., GCM projections**

**2. Changing vegetation and ecosystem dynamics**



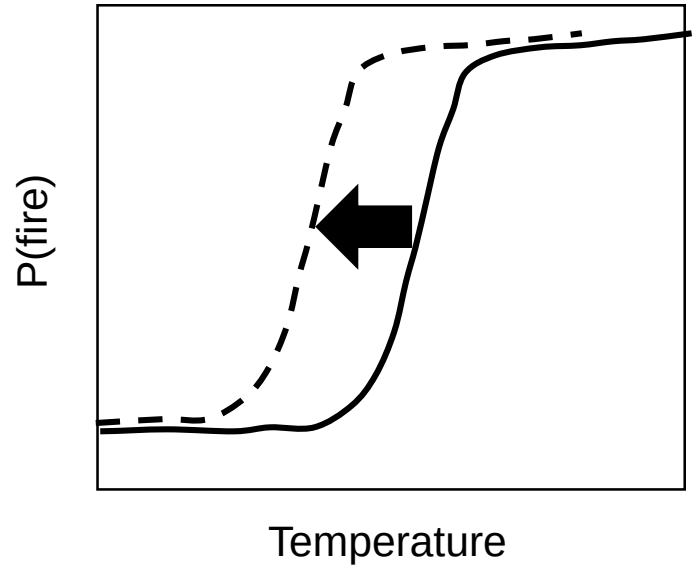
**Changing fire-climate relationships**

# Limitations to future projections

**Why might projections be wrong?**

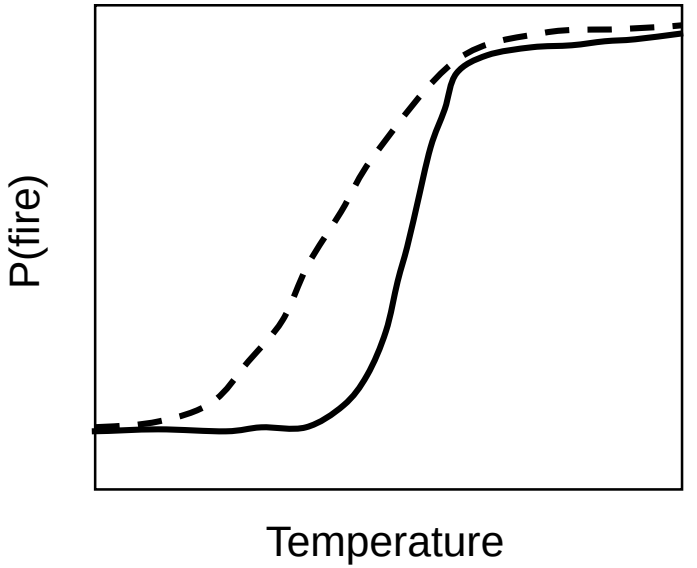
**1. Data biases or errors**

- **Modify value of temperature threshold**




**2. Changing fire-climate relationships**

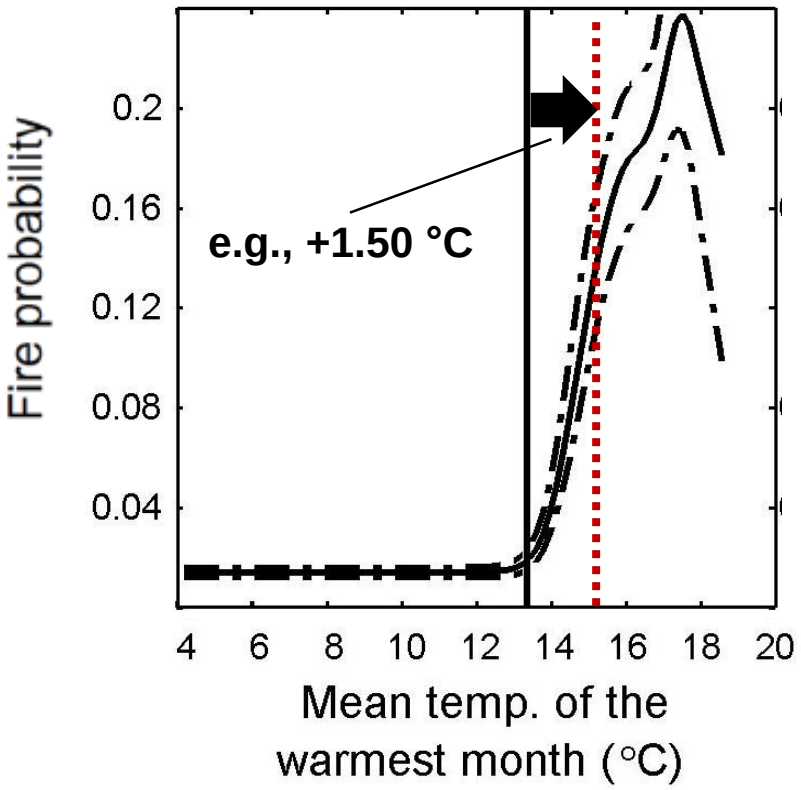
- **Modify shape of relationship**



# Modifying fire-climate relationships

***Evaluate sensitivity of model predictions to slight changes in original relationships***

## Modify threshold values




## Three Modifications

**+0.50 °C**

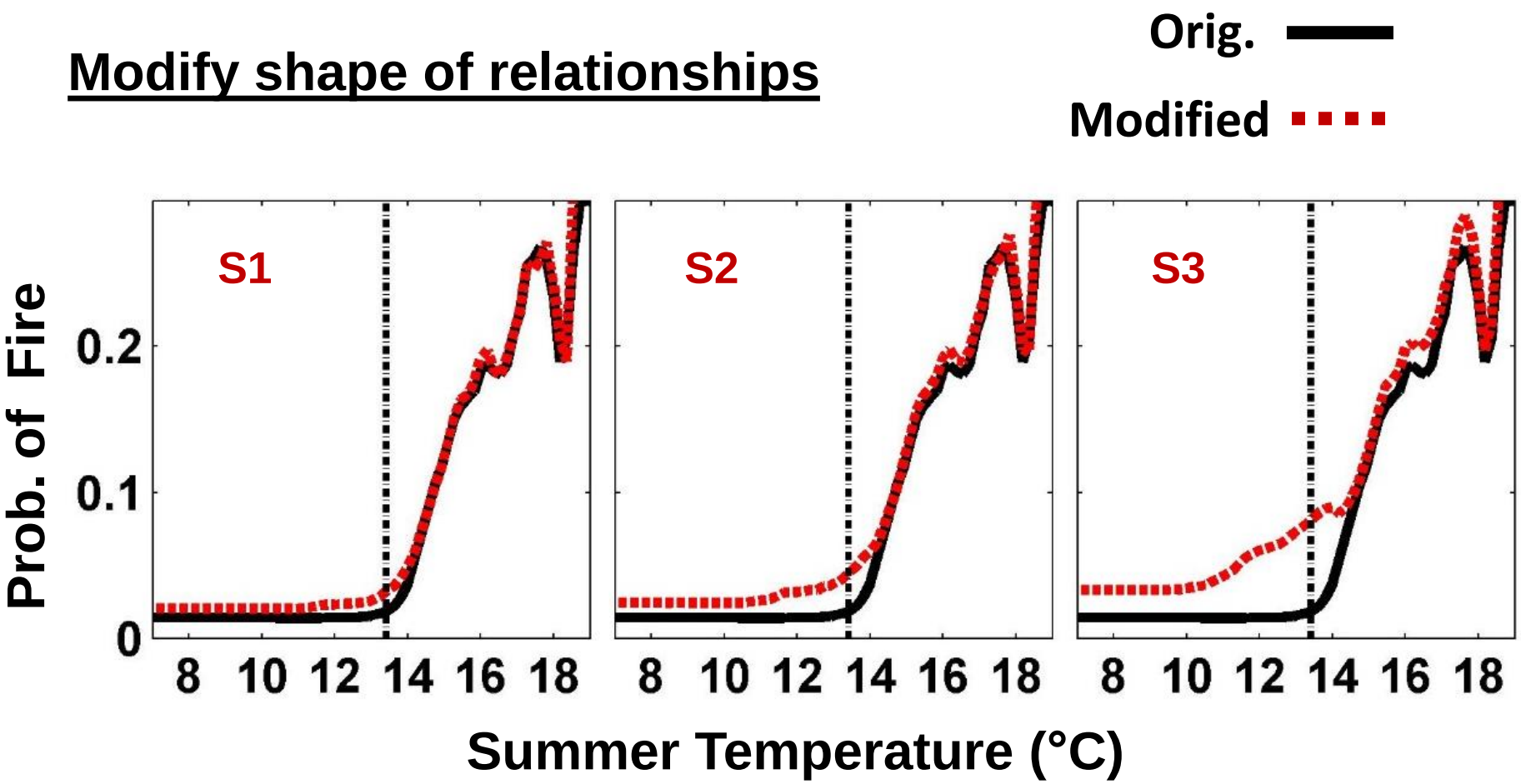
**+1.00 °C**

**+1.50 °C**

# Modifying fire-climate relationships

***Evaluate sensitivity of model predictions to slight changes in original relationships***

**Modify shape of relationships**



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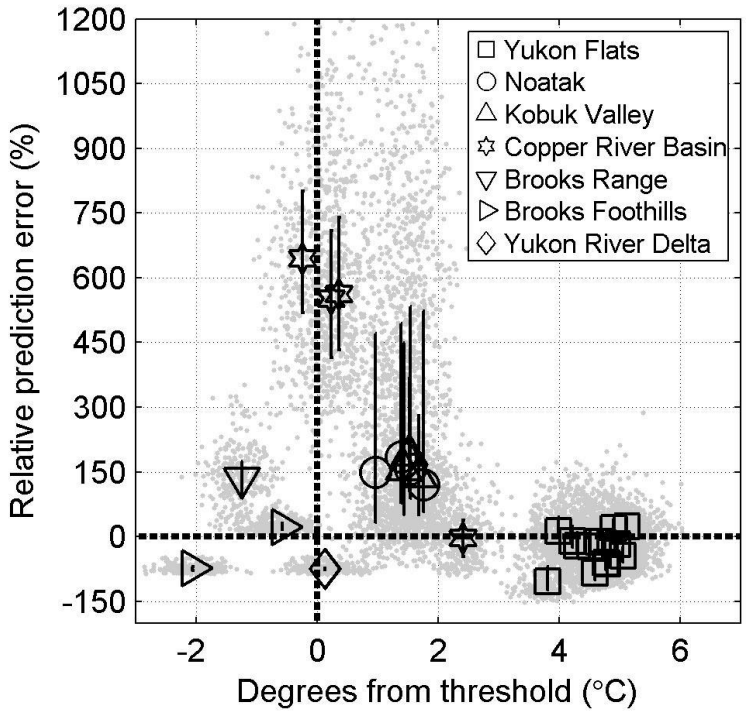
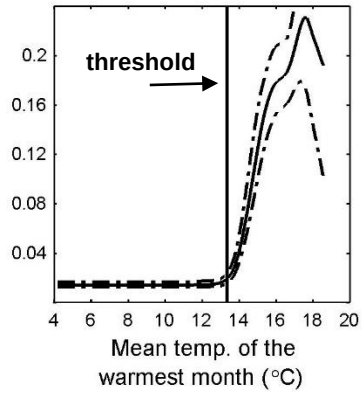
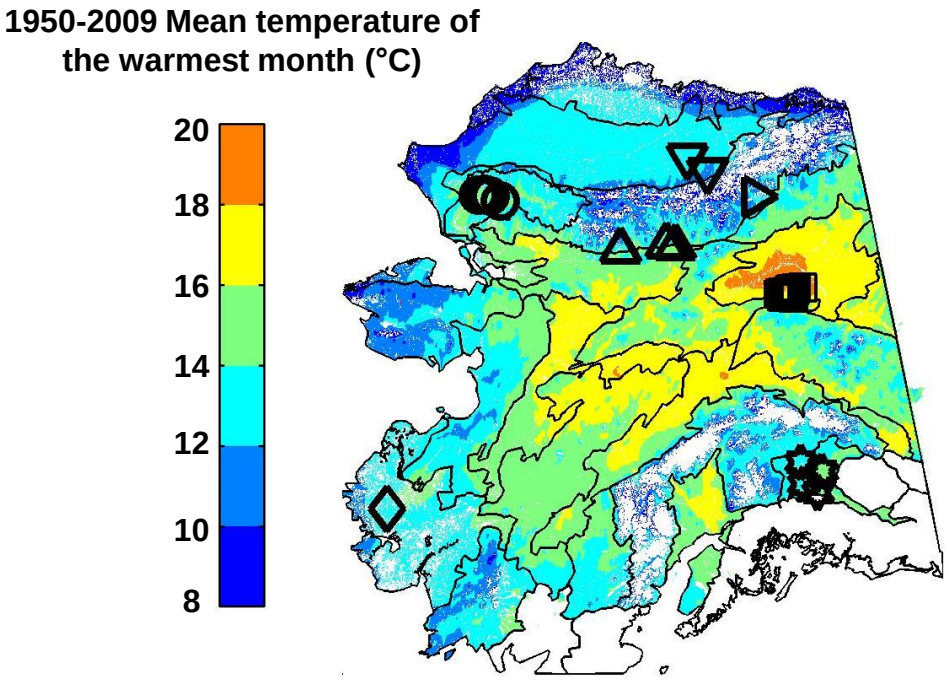
2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

# Q1: How do thresholds impact statistical predictions outside the observational range?



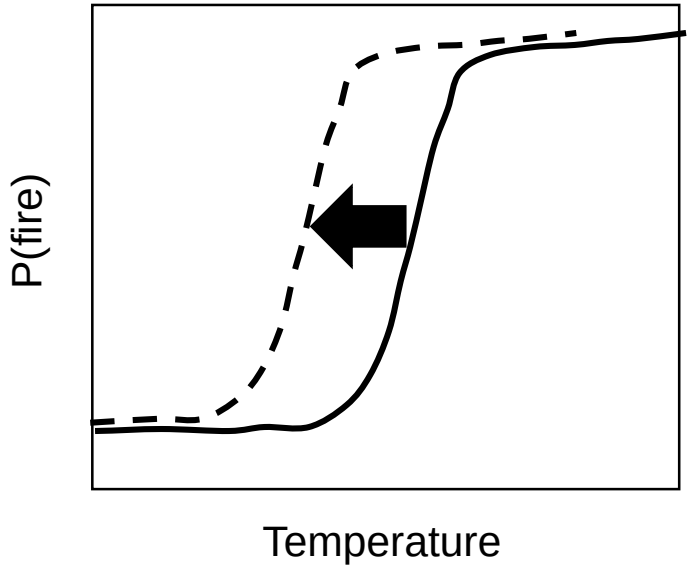




***Prediction error varies as a function of threshold proximity**

# Why might projections be wrong?

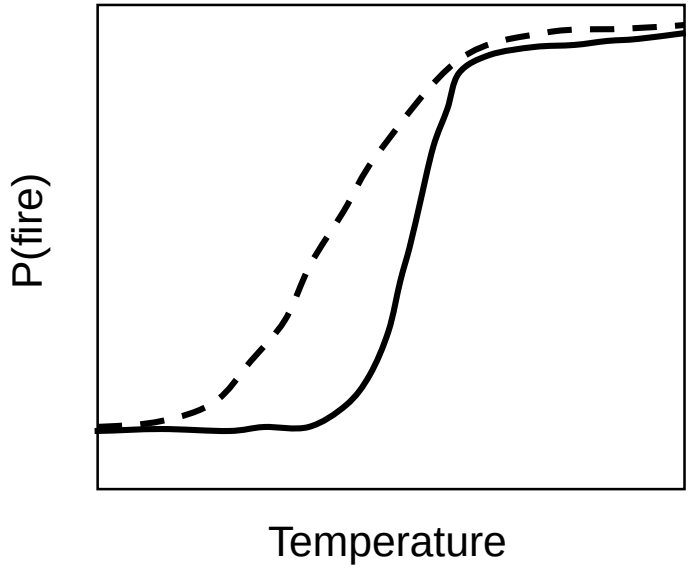
**1. Data biases or errors**

- **Modify value of temperature threshold**




**2. Changing fire-climate relationships**

- **Modify shape of relationship**



# Q2: How sensitive are predictions to modified fire-climate relationships?

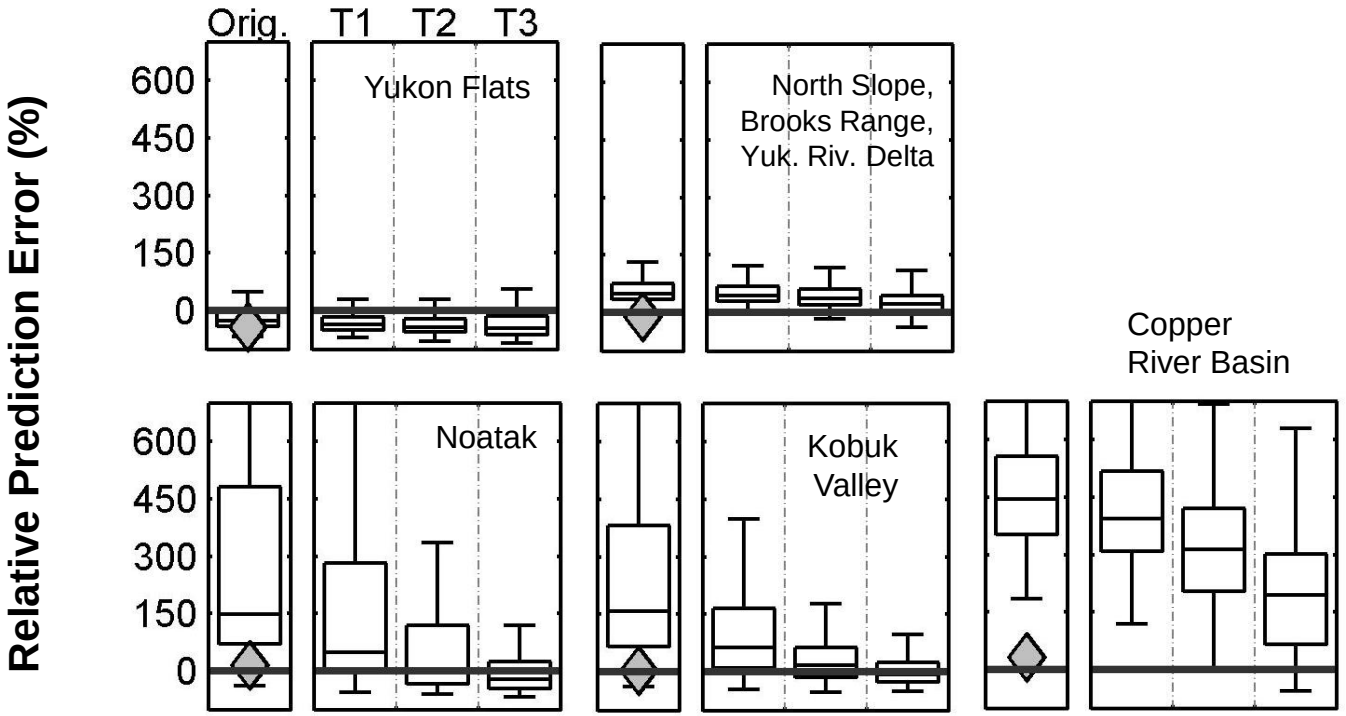
**Modified threshold values**

**T1:** **+0.50 °C**

**T2:** **+1.00 °C**

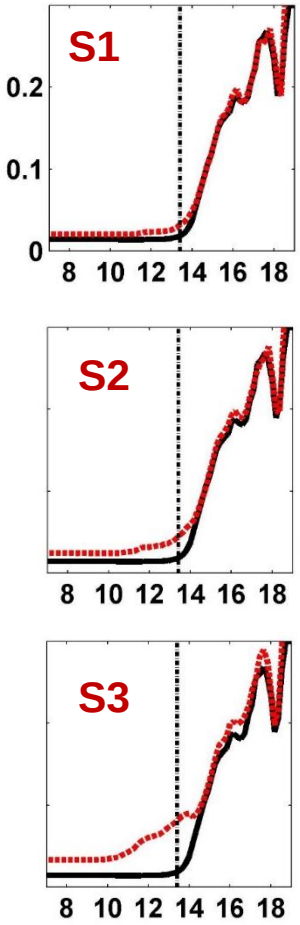
**T3:** **+1.50 °C**

**Prediction error (1950-2009)**

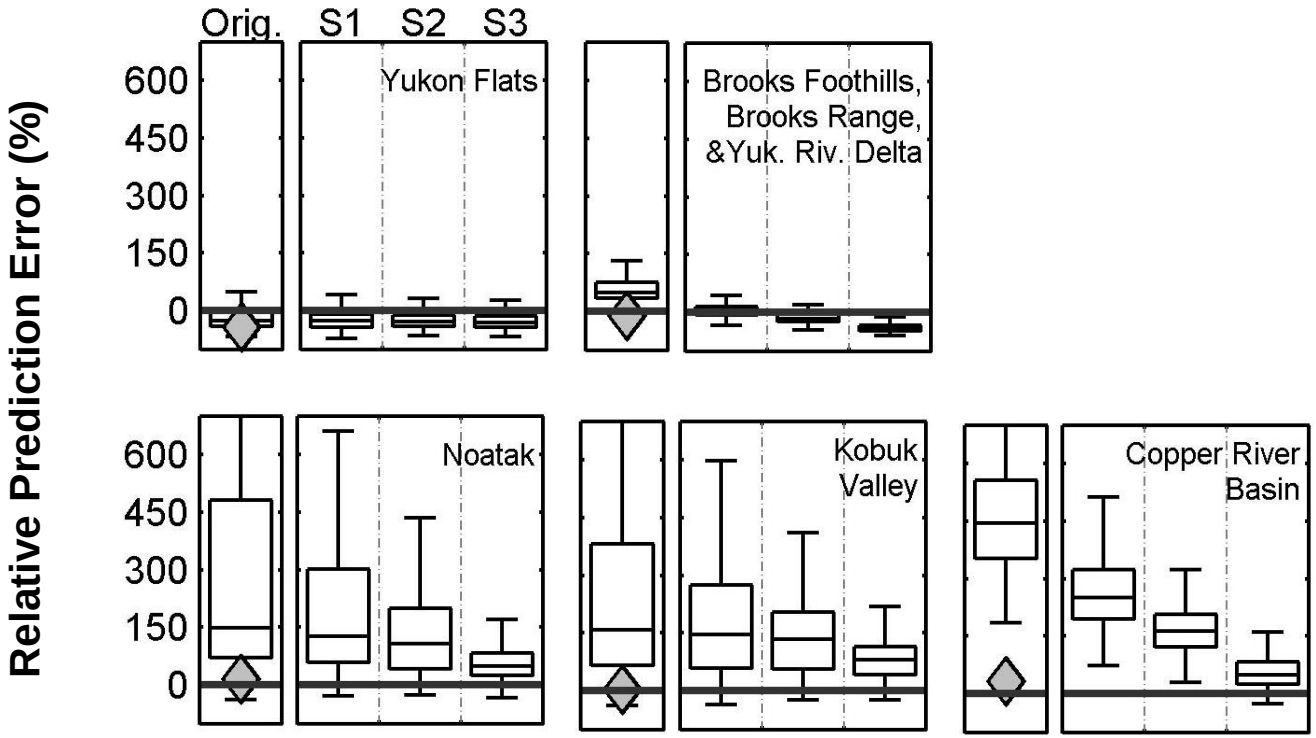


# Q2: How sensitive are predictions to modified fire-climate relationships?

## Modified relationship shapes




Prediction error (1950-2009)



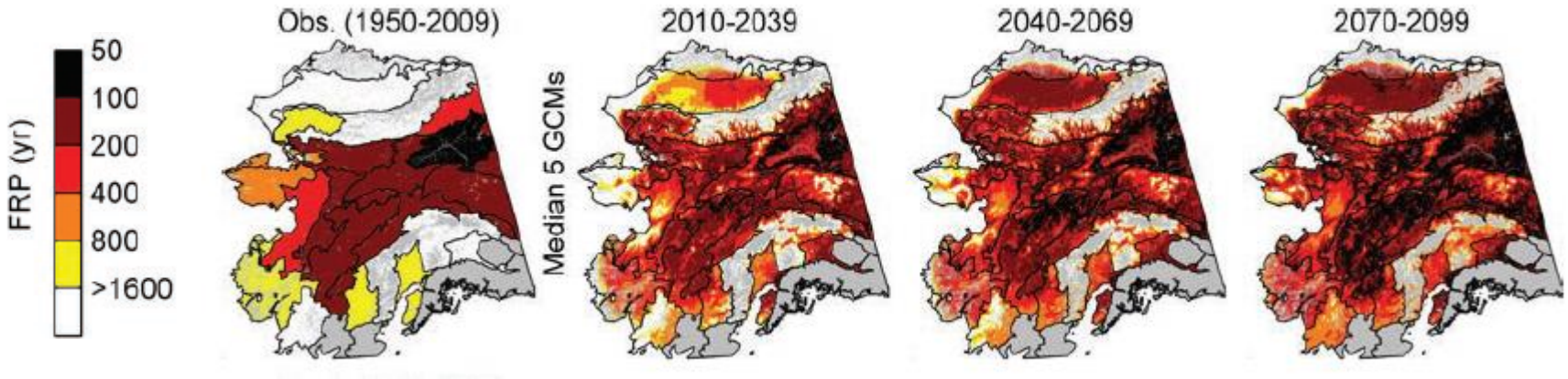

***Uncertainty can arise from even small changes in fire-climate relationships**

# Implications for future predictions

# Implications for future predictions

**Q3: How do nonlinear, threshold relationships impact our ability to predict future conditions?**

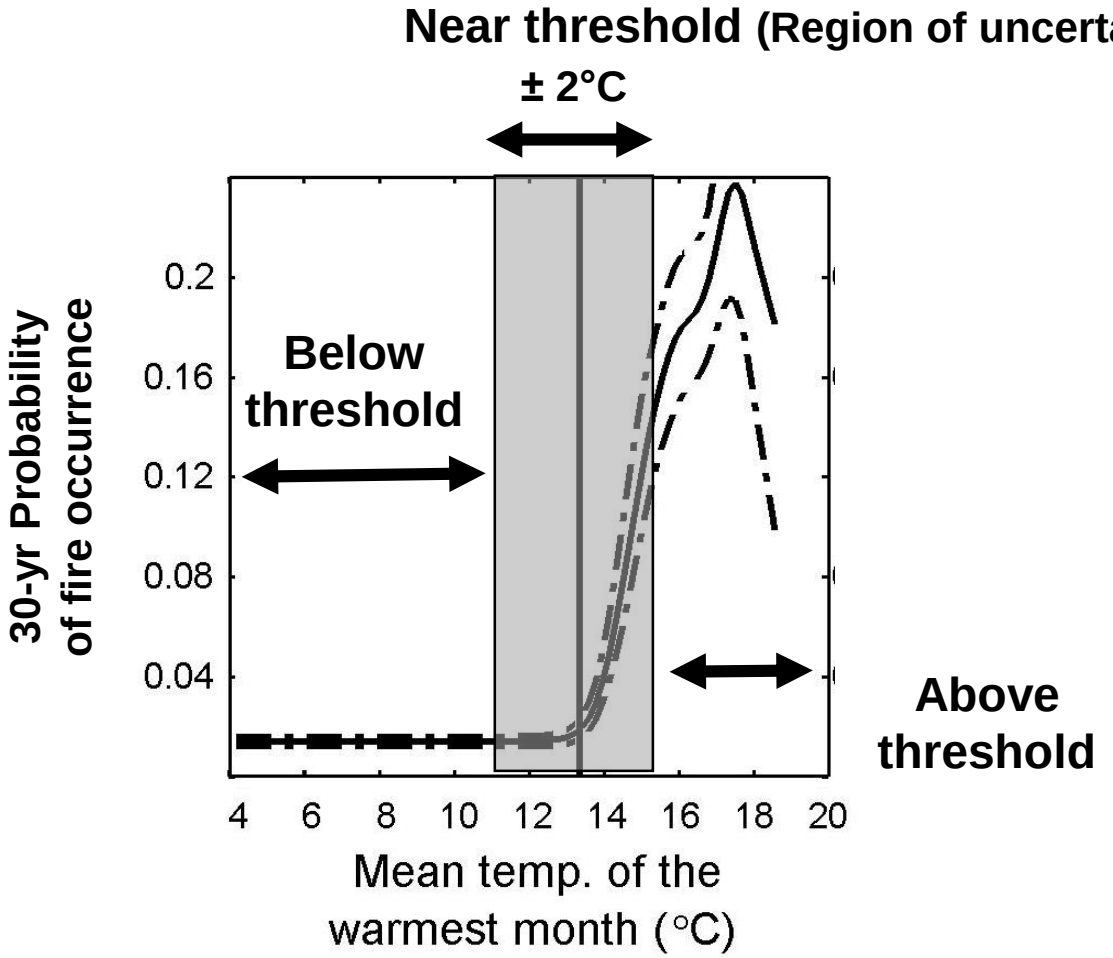
**Projected changes in fire activity**



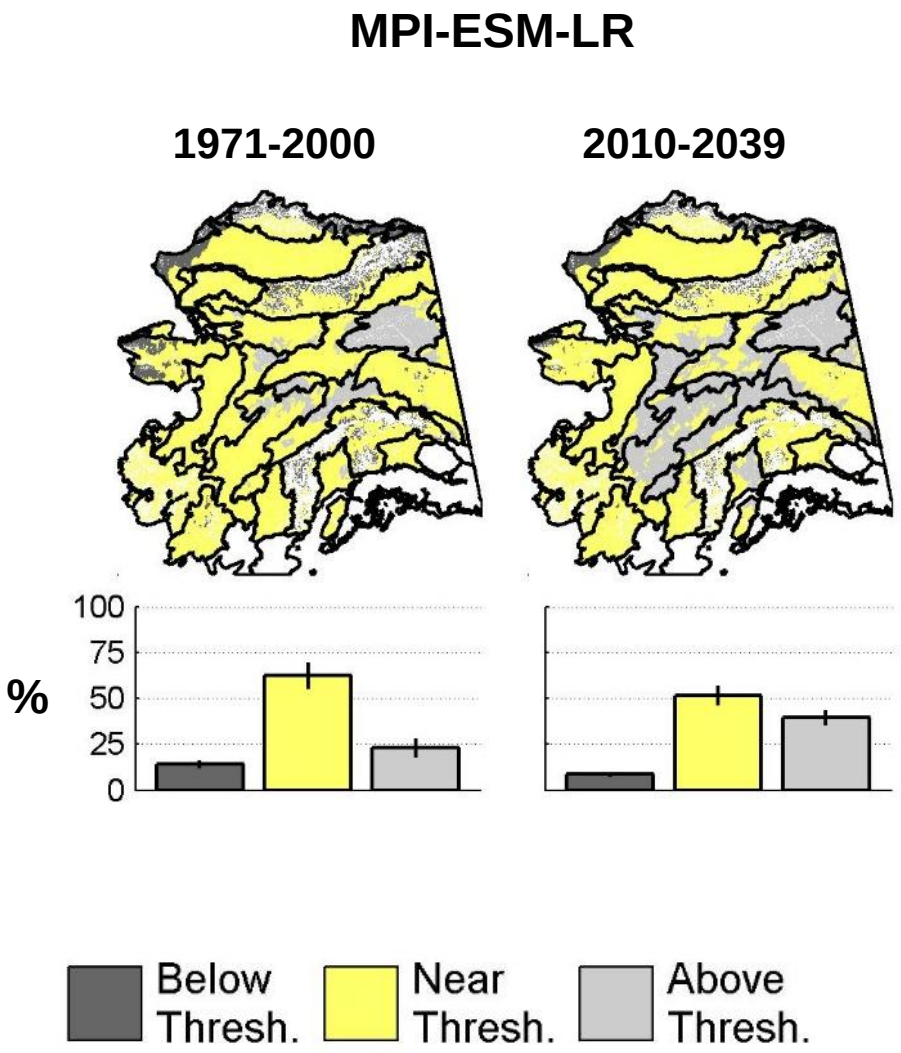

*Young et al. (2017) Ecography*

# Implications for future predictions

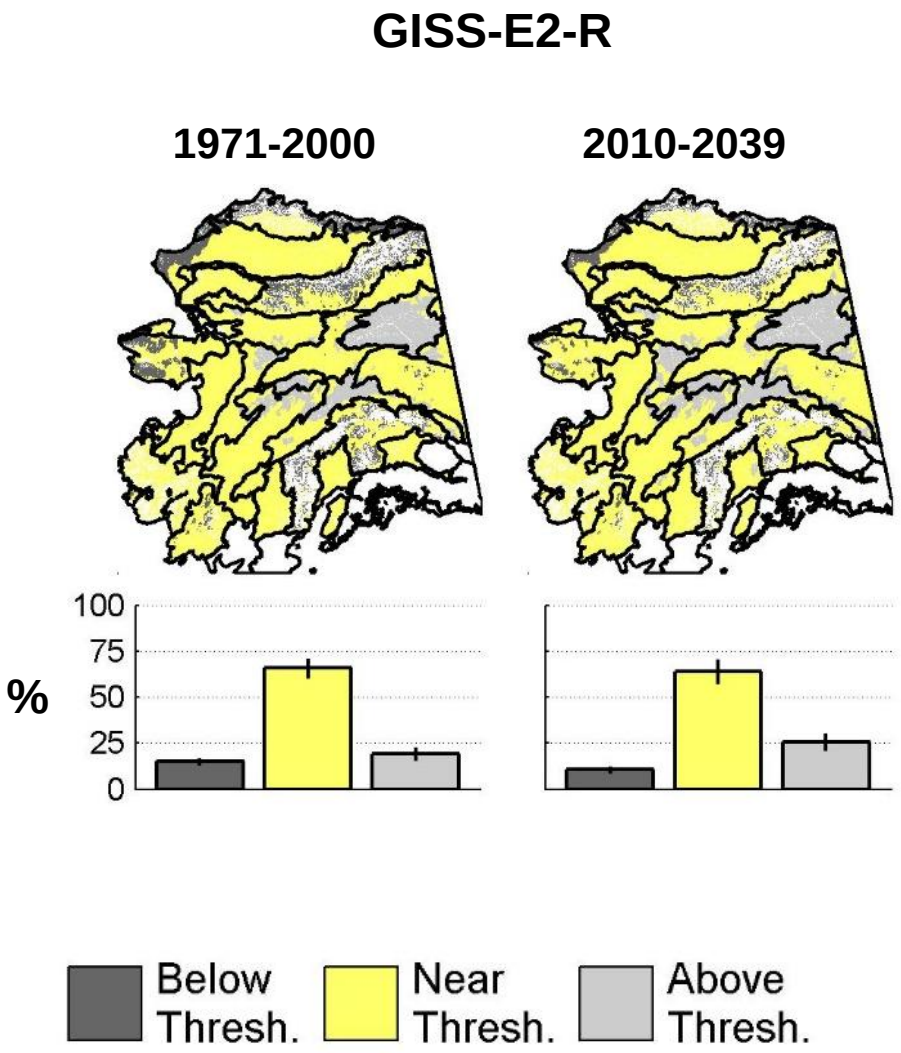
**Q3: How do nonlinear, threshold relationships impact our ability to predict future conditions?**



# Implications for future predictions



# Implications for future predictions



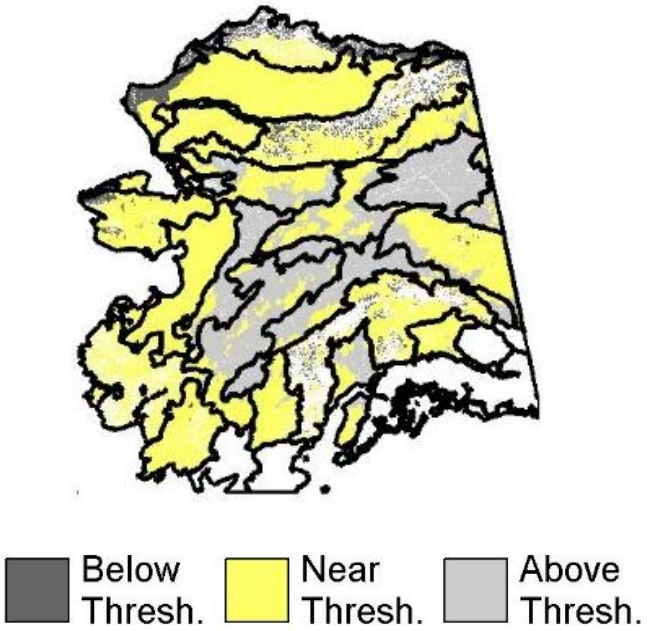
# Implications for future predictions

**** Threshold-driven uncertainty will vary across AK regions in the 21st century.***

**What are the spatial patterns?**

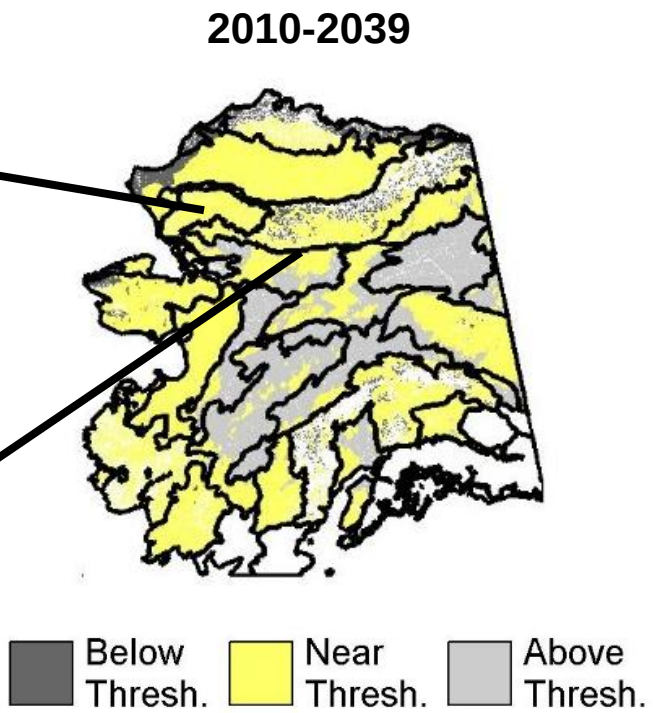
**MPI-ESM-LR**

**2010-2039**



# Implications for future predictions

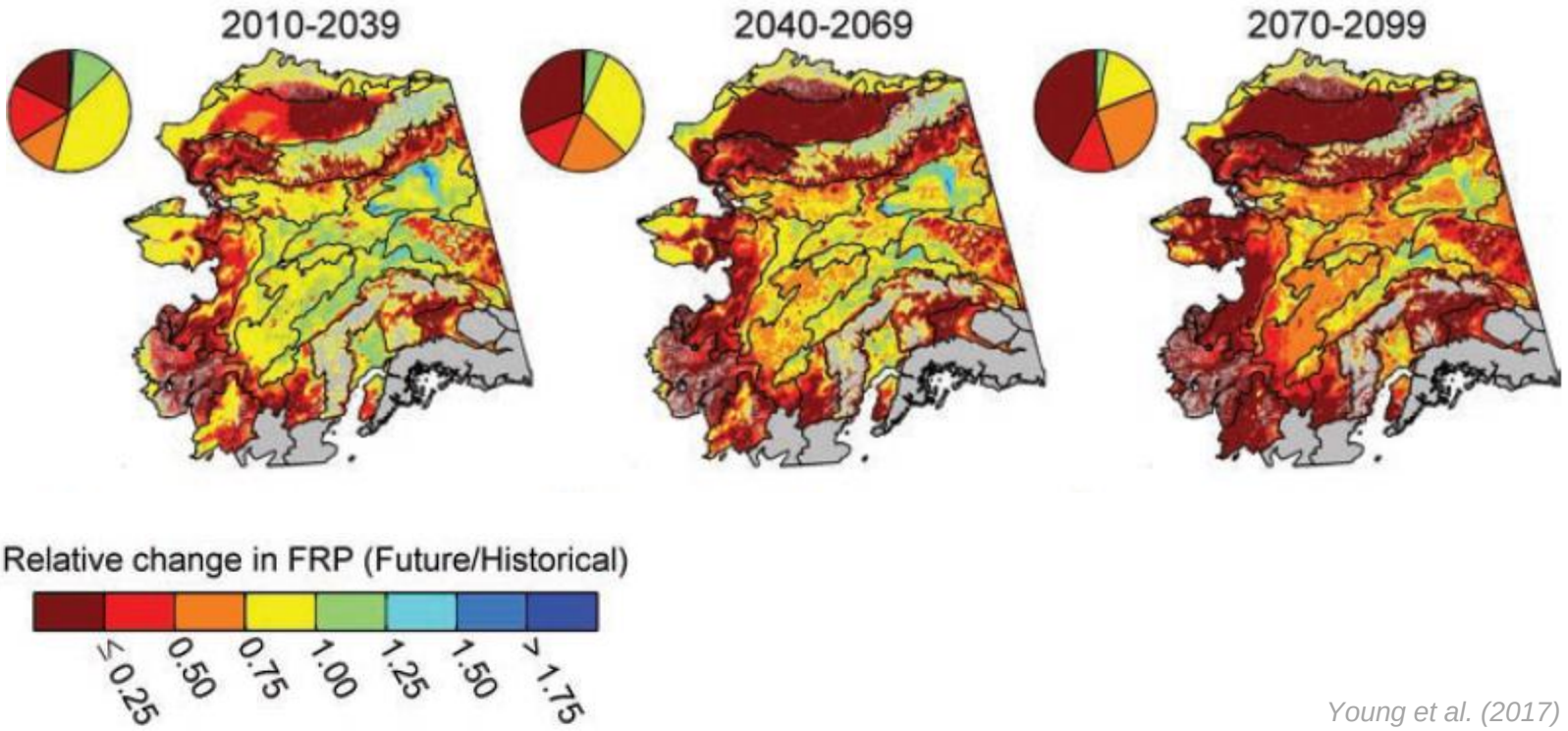
**** Tundra and forest tundra dominate areas of highest uncertainty***



# Implications for future predictions

**** Tundra and forest tundra dominate areas of highest uncertainty***

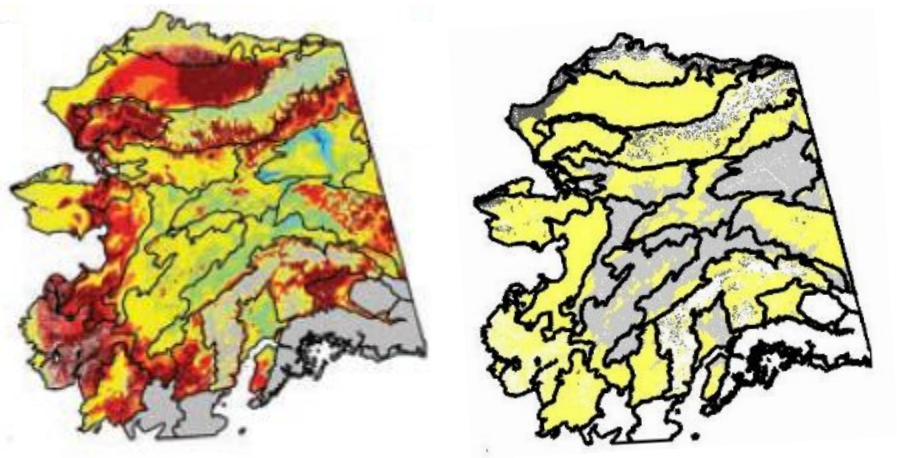
**** Regions also most vulnerable to fire-regime shifts***




*Young et al. (2017) Ecography*

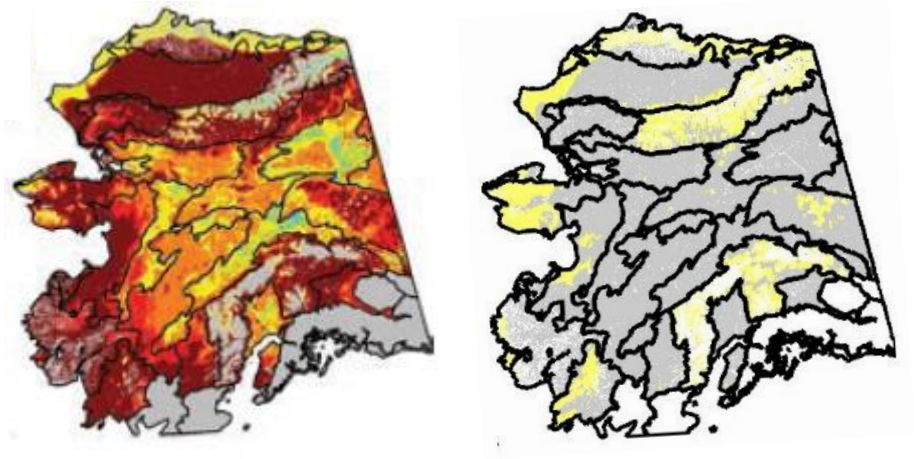
# Implications for future predictions

2010-2039

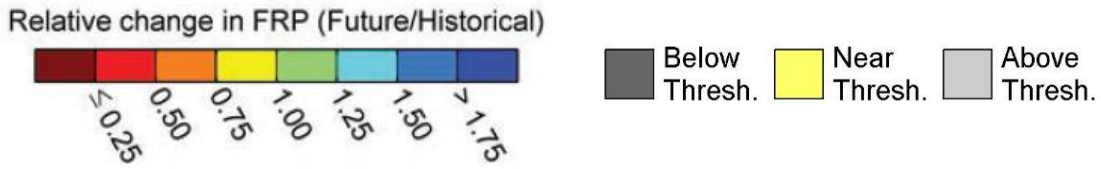


*** Projections accompanied by higher uncertainty***

2070-2099

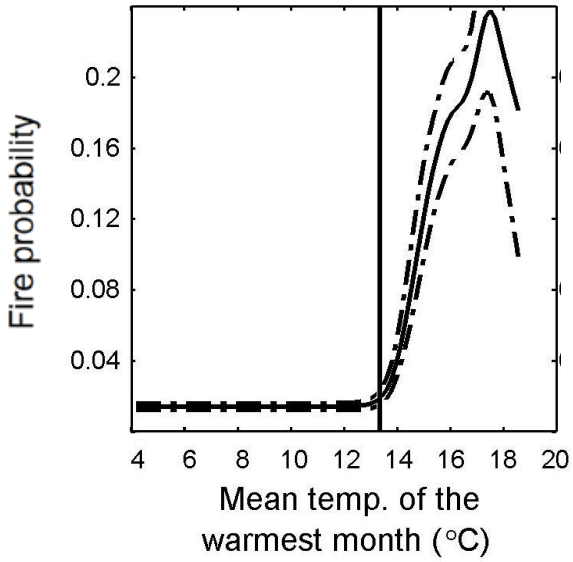


*** Projections have less uncertainty as climate moves beyond thresholds***



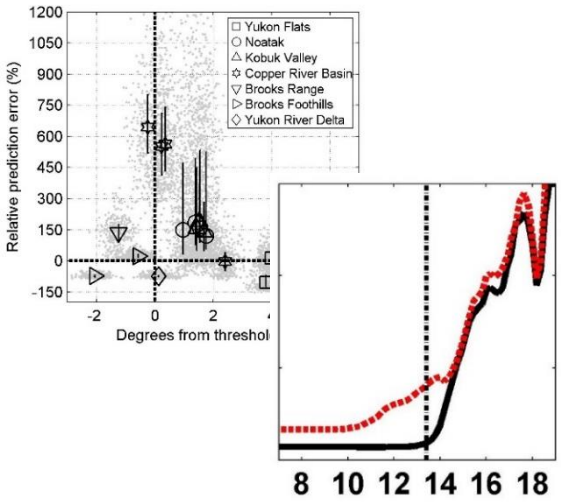
# Caveats and considerations

- **Only consider one explanatory variable (temperature)**
- **Do not consider interactions among different driving variables (e.g., temperature and precipitation)**
- **Only looked at one modeling tool (i.e., boosted regression trees)**

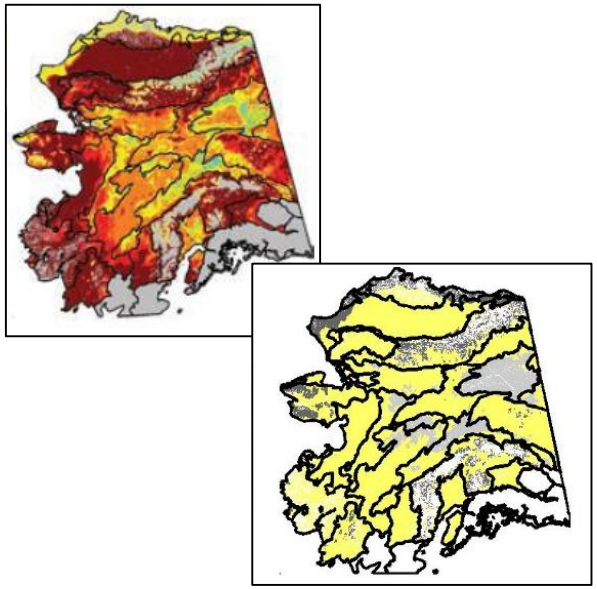


# Conclusions

- **Uncertainty varies in relation to threshold proximity, and predictions are sensitive to minor modifications**




- **Threshold-driven uncertainty will vary across AK regions in the 21st century.**



- **Anticipating fire-regime shifts may be accompanied by less threshold-caused uncertainty at the end of century**

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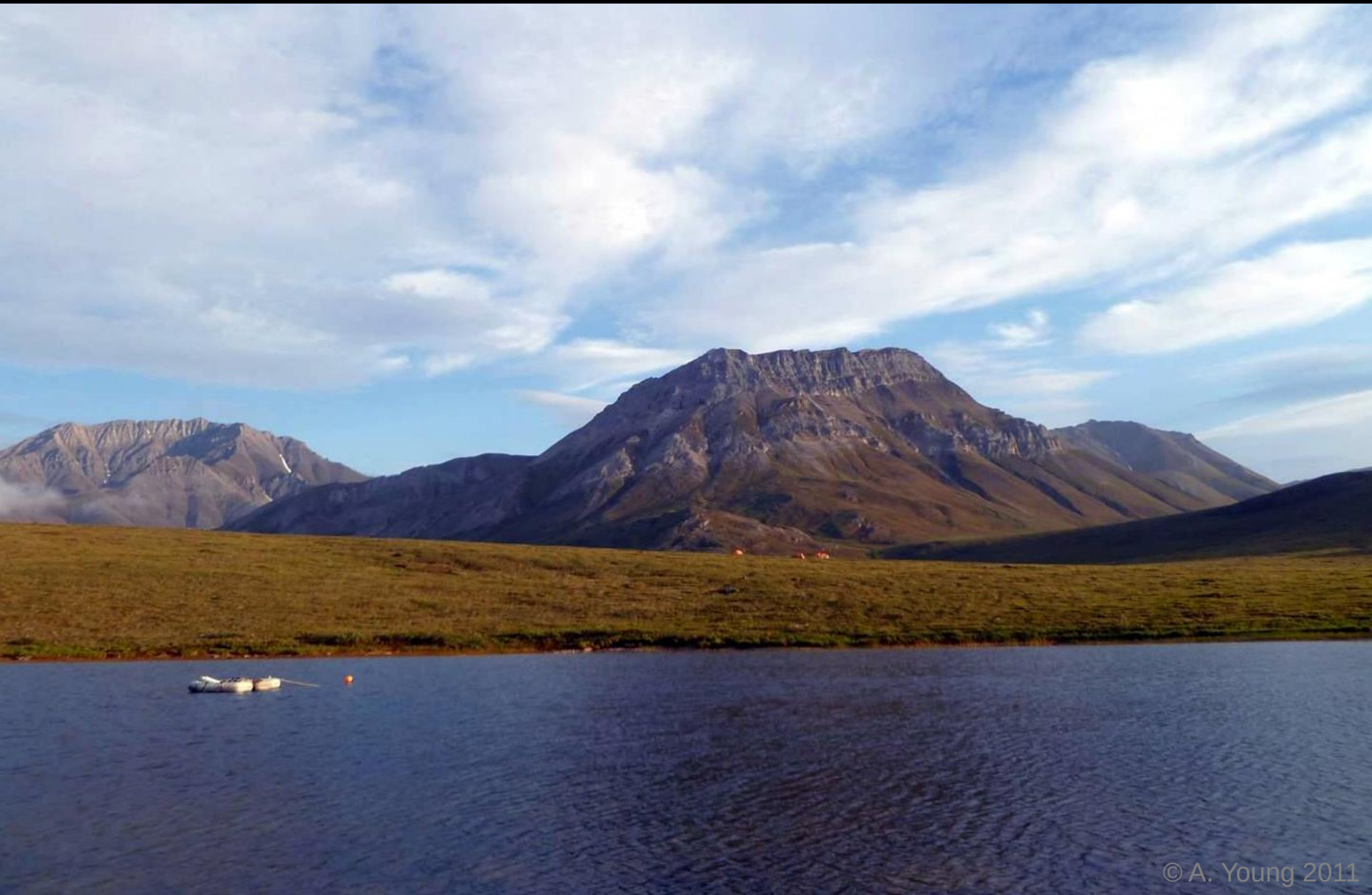
Award NNX14AK86H

# Questions?



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# Data Sources

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| Modeling Center | Institute ID | Model Name |
|---|---|---|
| NASA Goddard Institute for Space Studies | NASA GISS | GISS-E2-R |
| Max Planck Institute for Meteorology | MPI-M | MPI-ESM-LR & MPI-ESM-P |
| Meteorological Research Institute | MRI | MRI-CGCM3 |

†Data retrieved from Earth System Grid Federation: https://esgf.llnl.gov/